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ROYAL AERONAUTICAL SOCIETY 1866

Journal

of

THE ROYAL AERONAUTICAL SOCIETY

FEBRUARY 1956

CONTENTS

SECRETARY'S NEWS LETTER

NOTICES

CAPTAIN A. G. LAMPLUGH—AN APPRECIATION

THE SKID-RESISTING PROPERTIES OF WET SURFACES AT HIGH SPEEDS: EXPLORATORY MEASUREMENTS WITH A SMALL BRAKING FORCE TRAILER — C. G. GILES AND F. T. W. LANDER

THE CO-ORDINATION OF AERONAUTICAL RESEARCH IN THE BRITISH COMMONWEALTH — L. P. COOMBES

AERIAL SYSTEMS FOR AIRCRAFT — R. A. BURBERRY

PLASTICS STRUCTURES — G. C. HULBERT

THE PROVISION OF AERODROME OBSTRUCTION DATA FOR RATIONAL CODE CIVIL AIR TRANSPORT OPERATIONS — F. C. PETTS

TECHNICAL NOTES

Reciprocation of Triply-Partitioned Matrices—W. J. DUNCAN. Loss Due to Leakage in Unshrouded Radial Impellers—L. G. VALDENAZZI. Note on the Bending of a Finite Parallelogramic Plate Under Continuous Non-Loading—K. I. MCKENZIE and M. ROTHMAN. The Lift on Wings at Sonic Speeds by Means of an Electrical Resistance Analogue—P. J. PALMER. Pilot Training—WILLIAM COURTENAY.

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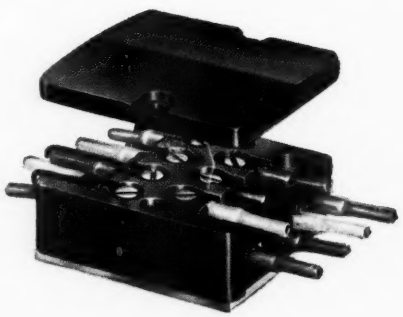

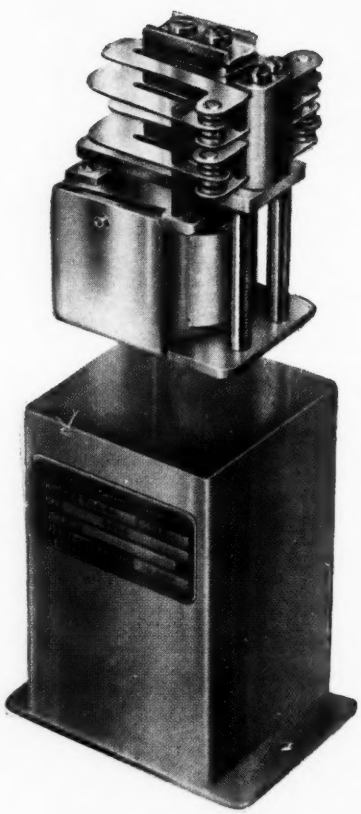

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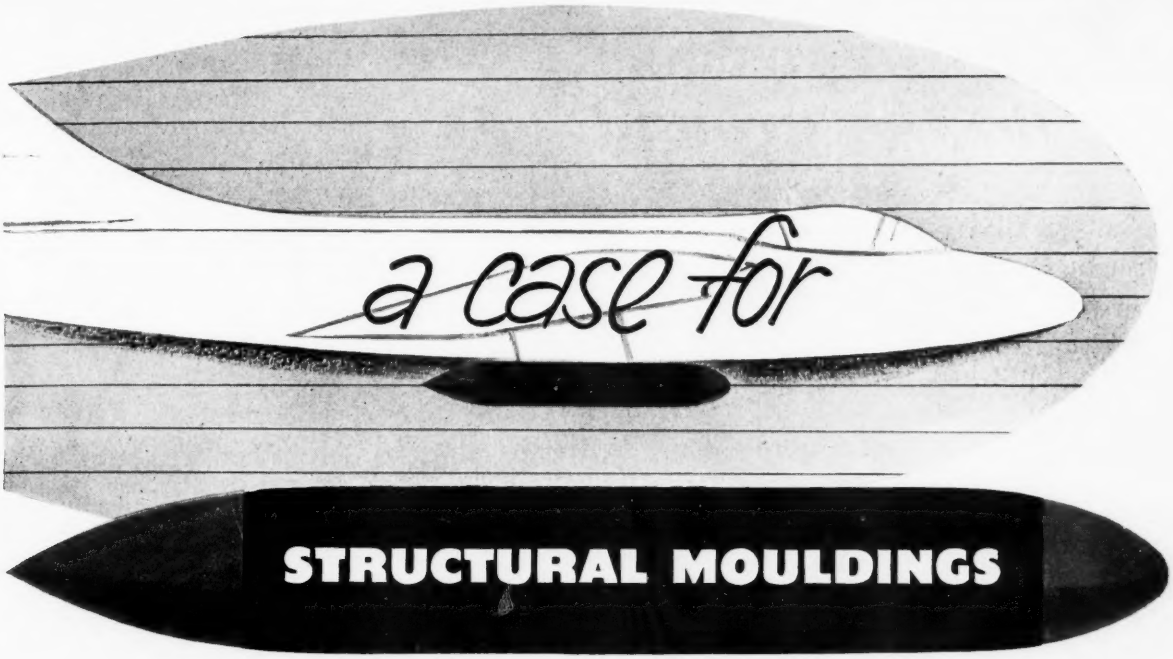

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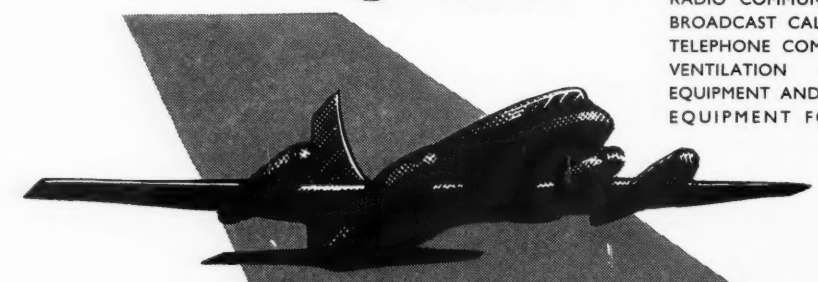

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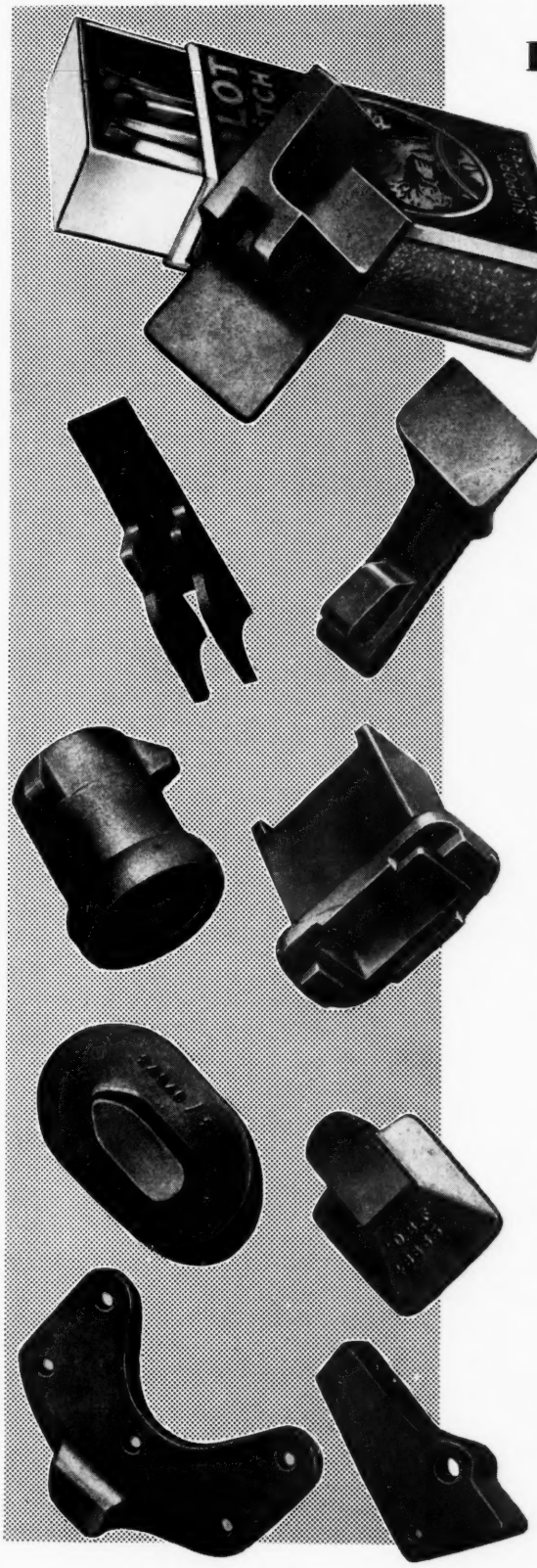

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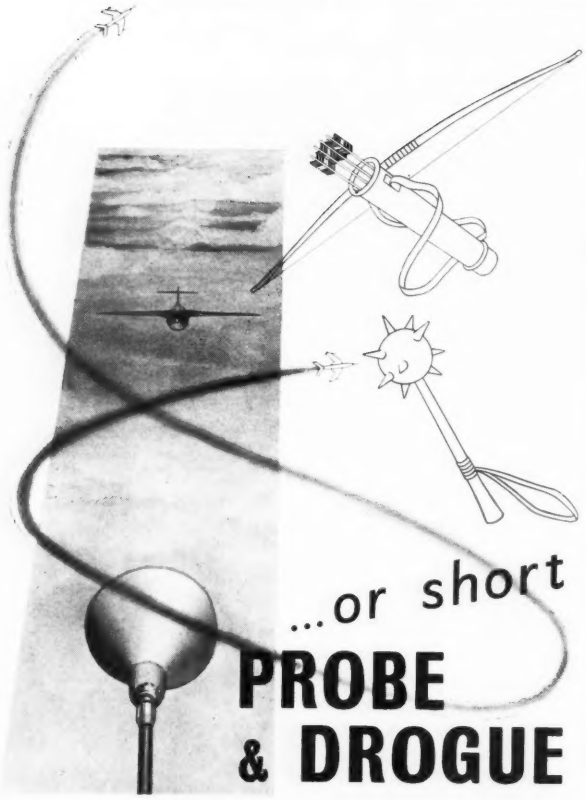

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Volume VII FEBRUARY 1956 Part 1

CONTENTS

Creep Buckling
N. J. Hoff

Supersonic Bangs Part I
P. S. Rao

Early Thoughts on the Jet Flap
B. S. Stratford

The Mathematical Theory of "Hysteretic Damping"
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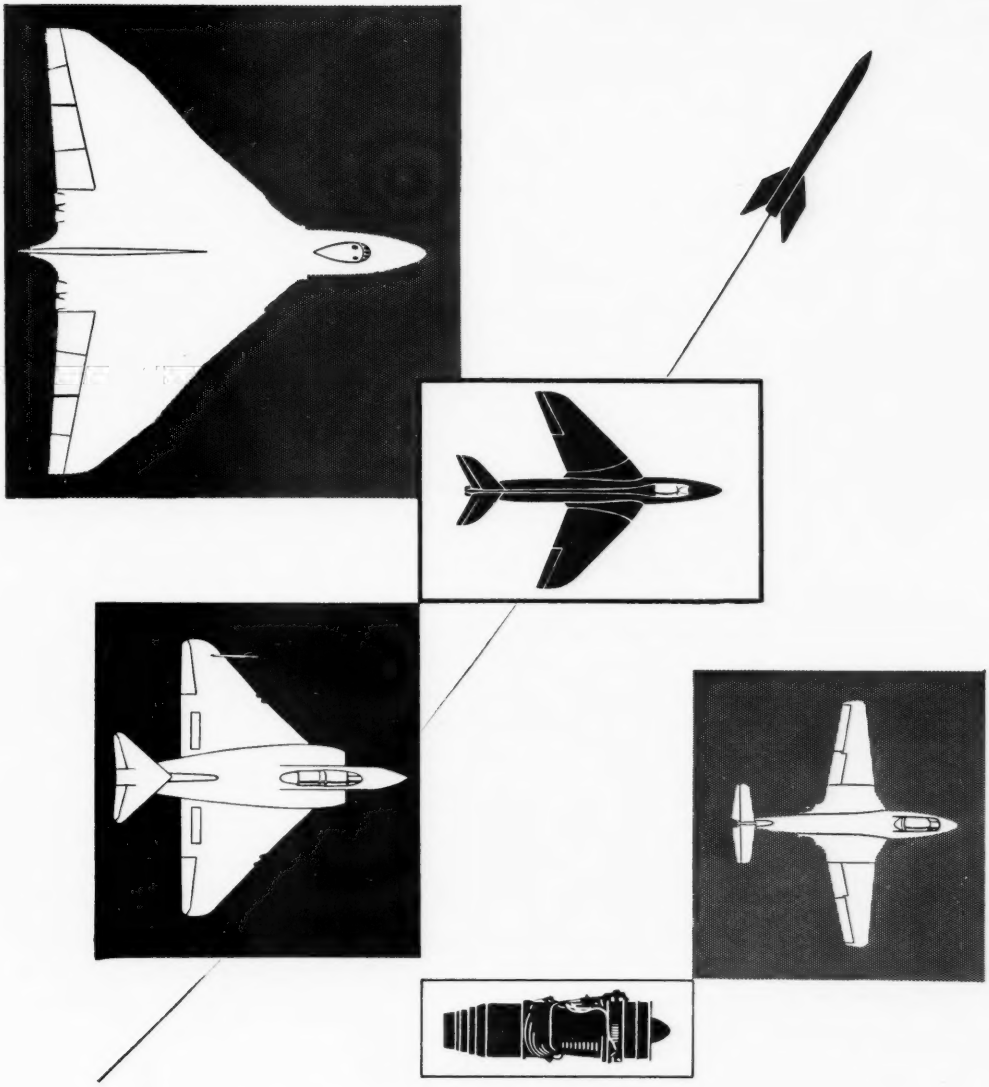

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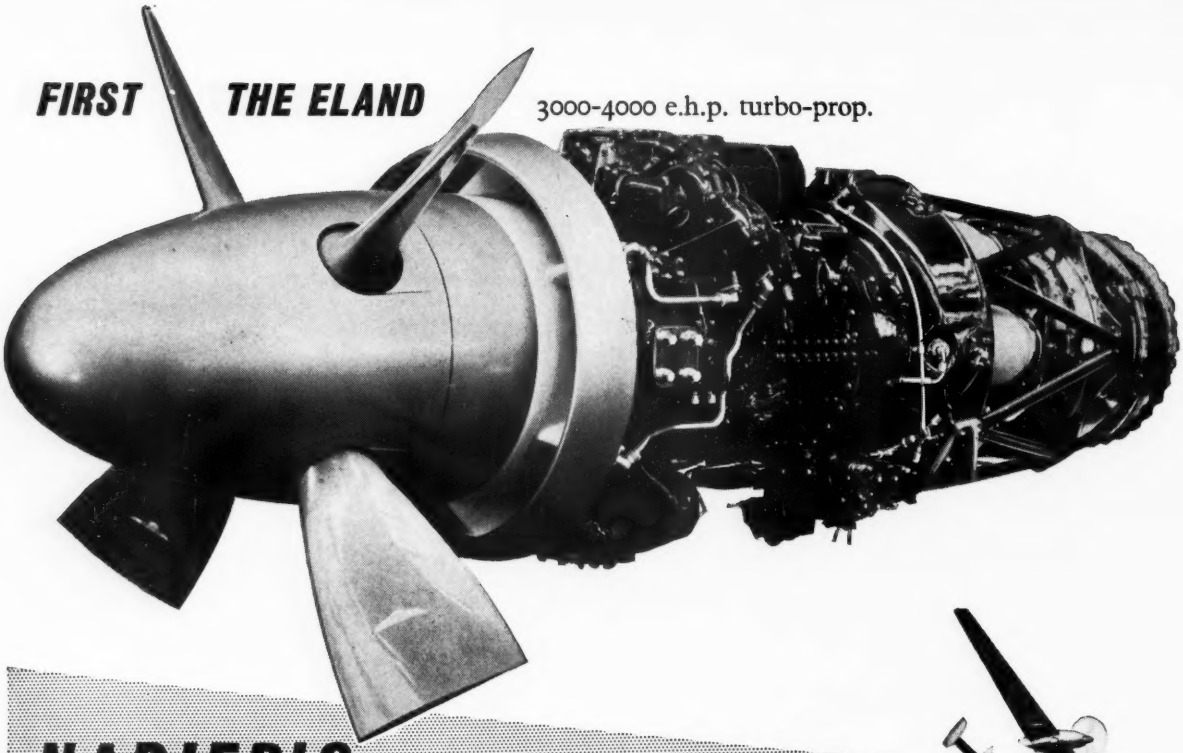

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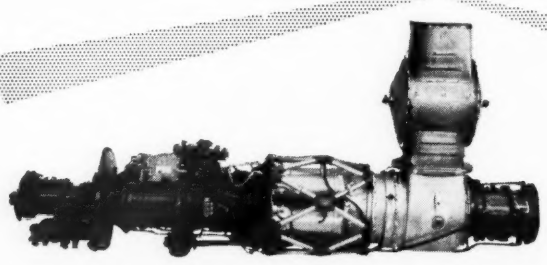

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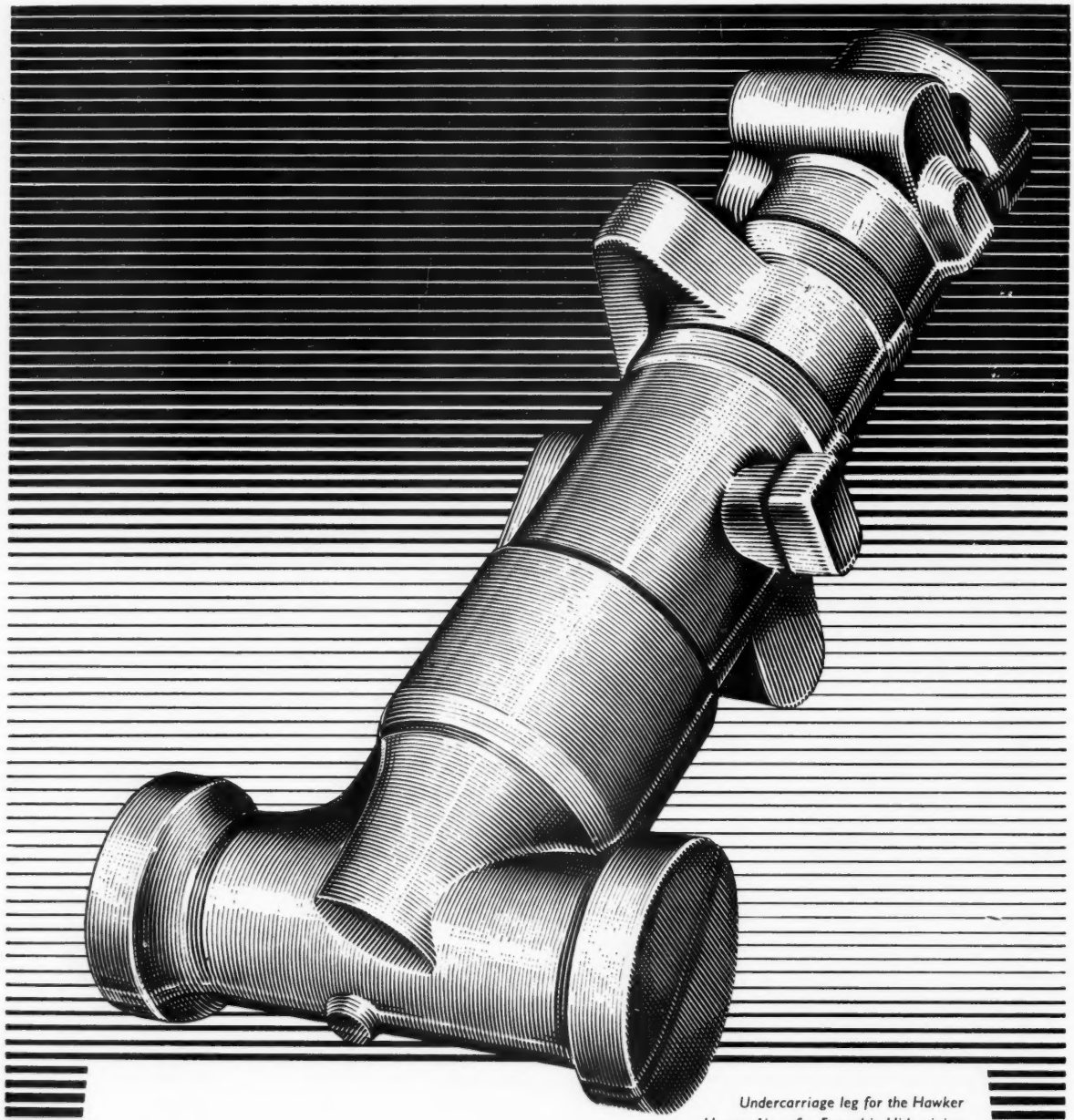

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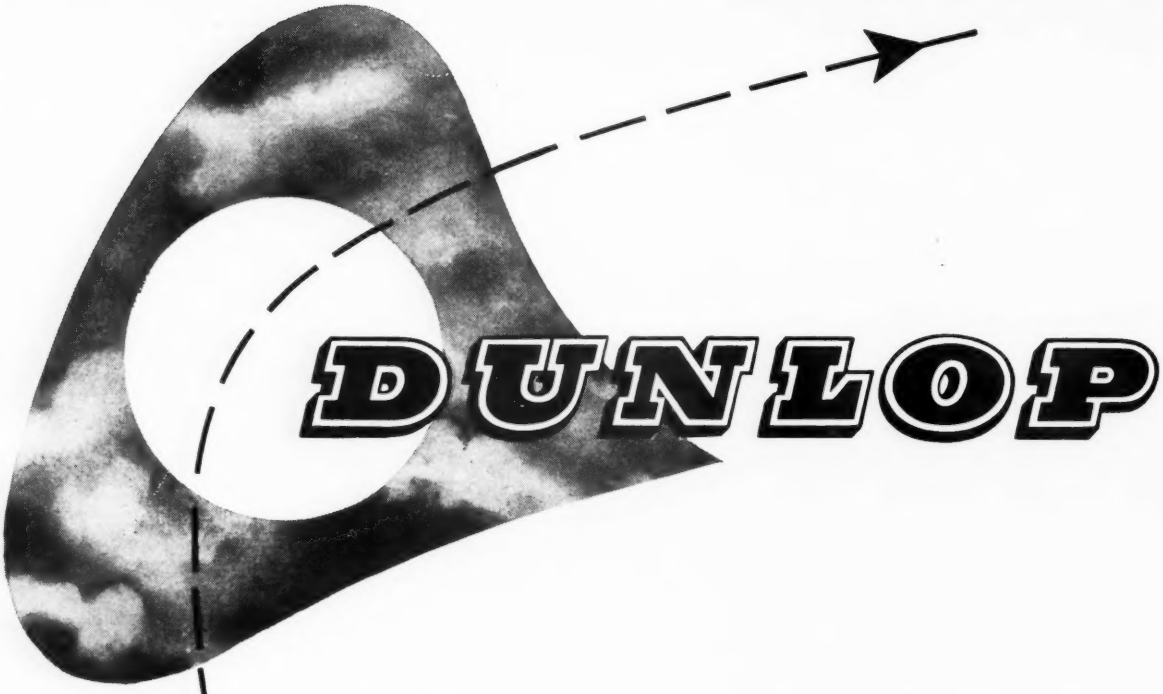

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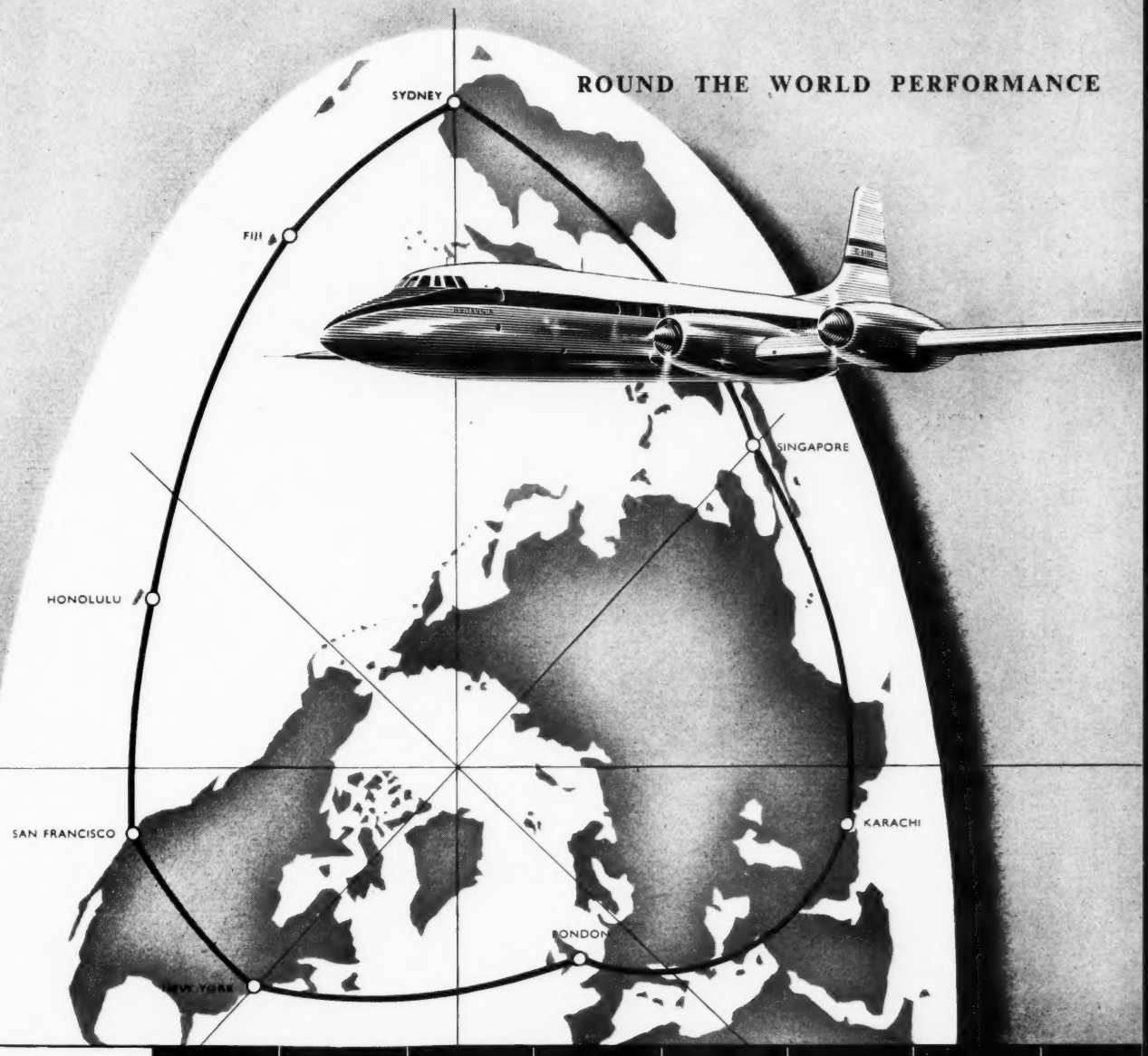

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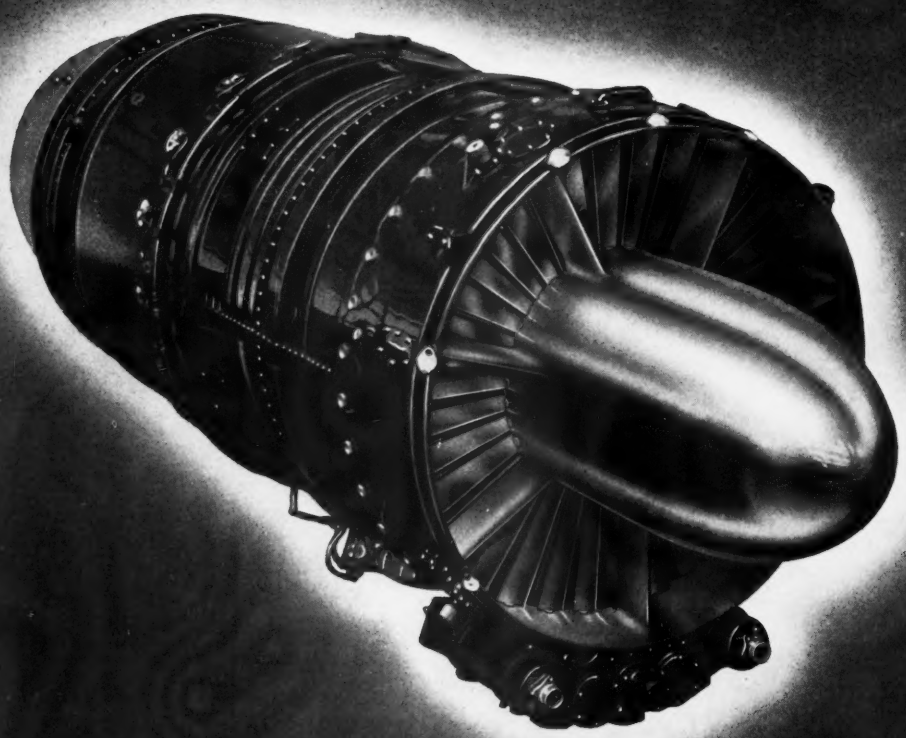

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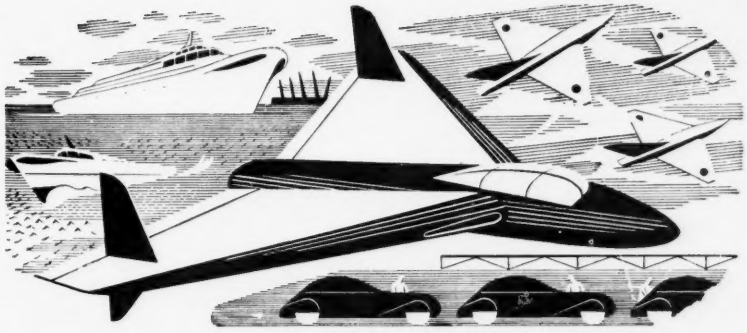

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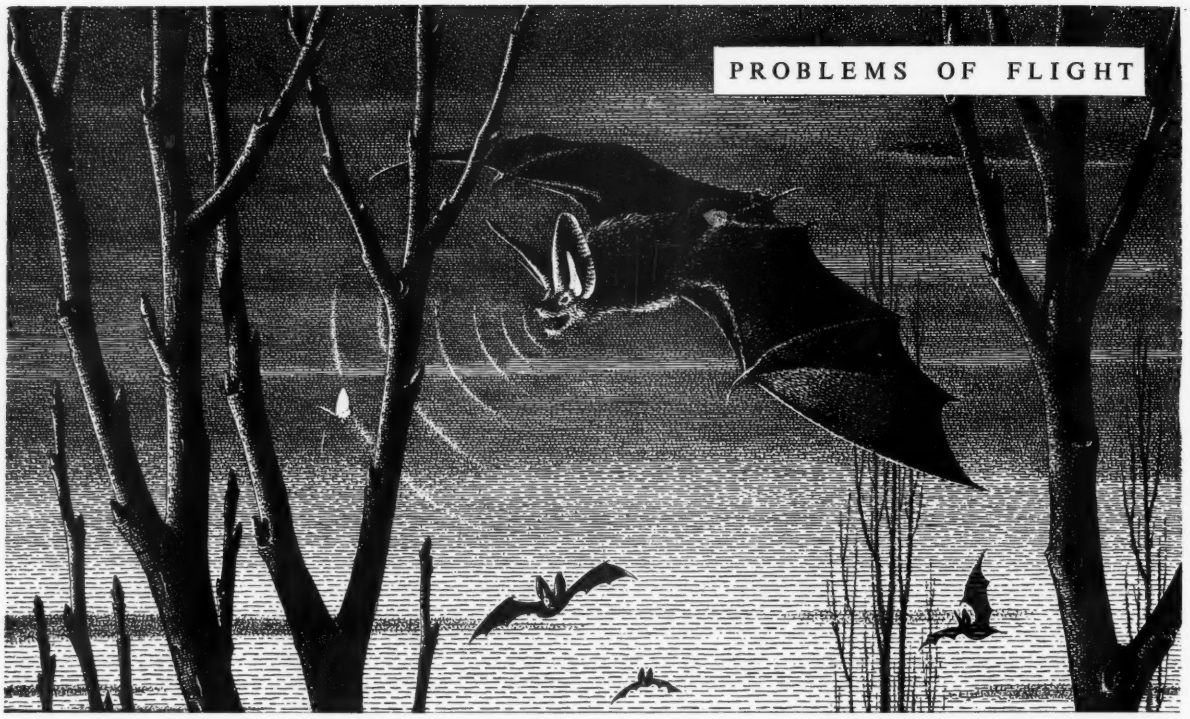
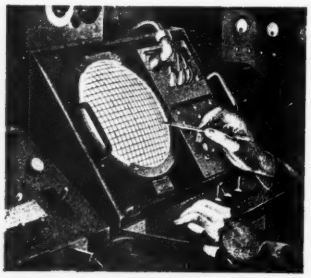


ECHO-LOCATION

THE technique of detecting invisibly-distant objects by reflected waves of impulses was an important factor in winning the war. It is now vital to the defence of the West, and of immense value to civil aviation. Radar is the latest of the various techniques of detection by reflection — but by no means the only one. The most ancient is the echo-location of the bat.

There are over two thousand species of bat. Some are carnivorous, one a vampire, some fruit-eating, and many live on insects. These last (including the British species) catch tiny flies and midges on the wing, darting erratically about as they hunt, but avoiding obstacles with uncanny precision even in darkness. Recently a bat was blindfolded: it still steered rapidly and accurately. But when its ears were covered it blundered helplessly into plainly-visible obstacles. The bat's technique of echo-location — proved by this experiment — is made possible by a remarkable development of special equipment. It emits a succession of bursts of supersonic vibrations from its larynx. These are at a frequency of around 50,000 per second. The bat's large ears pick up the echoes of these supersonic calls and by some almost incredibly rapid and exact mechanism inform the bat accurately about its surroundings. Its brain is developed to translate this information — which must be very complicated if the bat is flying in a crowded space — into instant action. If a crew laying a gun on the information of a radar-screen could achieve anything like the bat's speed and accuracy, anti-aircraft defences would be quite impenetrable.

Radar is becoming more and more important



in an offensive role, too: its powers of detection even in thick darkness make it invaluable to an interceptor. For this also the bat provides a precedent. His technique of echo-location is apparently so sensitive that he can detect with it even the tiny fast-flying midges he feeds on. If, again, we can ever begin to match with our radar the bat's efficiency, our interceptors will be formidable indeed.

The radar of a modern aircraft and the echo-location of the pre-historic bat are very different. But the techniques are comparable — and above all the purpose is the same. Here is yet another example of Nature anticipating, by thousands of ages, man's most revolutionary inventions.

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VOLUME 60 FEBRUARY 1956 NUMBER 542

CONTENTS

PAGE

Secretary's News Letter IX

Notices X

Nomination of Candidates for Council—New Year's Honours List 1956—Honours for Members—Convention on "Electrical Equipment of Aircraft"—Ninth Louis Blériot Lecture, Paris—Graduates' and Students' Section: Visits—Mond Nickel Fellowships—Acknowledgments—Diary—News of Members—Elections—Annual Subscriptions.

Captain A. G. Lamplugh—An Appreciation 81

The Skid-Resisting Properties of Wet Surfaces at High Speeds: Exploratory Measurements with a Small Braking Force Trailer
C. G. GILES AND F. T. W. LANDER 83

The Co-ordination of Aeronautical Research in the British Commonwealth
L. P. COOMBES 95

Aerial Systems for Aircraft R. A. BURBERRY 101

Plastics Structures G. C. HULBERT 114

The Provision of Aerodrome Obstruction Data for Rational Code Civil Air Transport Operations F. C. PETTS 121

Technical Notes 131

Reciprocation of Triply-Partitioned Matrices—W. J. DUNCAN. Loss Due to Leakage in Unshrouded Radial Impellers—L. G. VALDENAZZI. Note on the Bending of a Finite Parallelogramic Plate Under Continuous Non-Loading—K. I. MCKENZIE and M. ROTHMAN. The Lift on Wings at Sonic Speeds by Means of an Electrical Resistance Analogue—P. J. PALMER. Pilot Training—WILLIAM COURTENAY.

The Library 141

REVIEWS:—Morale in War and Work—Rotorcraft—The Third Service—Hydraulic and Pneumatic Operation of Machines—Jahrbuch 1954 der Wissenschaftlichen Gesellschaft für Luftfahrt—Aircraft Today—Tables of the Cumulative Binomial Probability Distribution—Boundary Layer Theory—Control of Insect Vectors in International Air Traffic—Nuclear Physics—Static and Dynamic Electron Optics—Flight Fly-Past—200 Miles Up—Aircraft Badges and Markings.

ADDITIONS TO THE LIBRARY. REPORTS.

All communications for publication in, and advertisements for, the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., Hon.F.C.A.I., A.F.I.A.S., A.F.R.Ae.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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Secretary's News Letter

February 1956.

MANY of you will know that Miss Barwood of the Society's staff has been awarded the M.B.E. To say that everyone is very pleased is yet another example of the British habit of understatement. Let us rid ourselves of our phlegm and say "Good Show", "Stout Fella" or any other phrase which shows extremity of pleasure. I have just glanced at the Year Book and have seen that since 1918, when Miss Barwood joined the Society staff, she has served four Secretaries, and that is an earnest of the service she has given to the Society and to the individual members who have sought advice or help (or both) and seldom gone away without. I am sure our Overseas members will welcome the news, for many of them have received many kindnesses. To the many messages of congratulations and good wishes which Miss Barwood has already received, I should like to convey to her those of the entire Membership of the Society.

The Society is arranging a Course of Lectures on Air Transport, which will be held at Christ Church, Oxford, from 4th April - 18th April 1956.

The Course of Study will cover, Air Transport Operation, Air Transport Economics, and Air Law.

Admission to the Course is open to employees of airline operators, to aircraft manufacturers, and others who might benefit by the Course.

As the number of students is limited, will anyone interested please write to me at once, and I shall forward the necessary details.

At the end of 1955 there appeared in the Journal an advertisement which stated that there were vacancies on the Technical Staff of the Society. These vacancies have not yet been filled; briefly I require two young graduates, one to help prepare the Data Sheets on Aerodynamics, and the second to work on the Structures Data Sheets. The salary will be commensurate with experience. If anyone wishes further information I shall be pleased to send it on request.

I have to record the formation of yet another Branch of the Society — at Christchurch (England) — and we wish it every success. The de Havilland Aeronautical Society has been granted permission by the Council to reform as the Christchurch Branch. It is planned to complete the re-organisation on 11th April 1956, at the Annual General Meeting of the de Havilland Aeronautical Society.

Mr. C. P. Homes has resigned from the Secretaryship of the Birmingham Branch, and is succeeded by his son, Mr. C. R. Homes. Mr. Homes Senior, became Secretary of the Branch in 1944, and it was largely due to his efforts that the Branch, despite the drop in membership, continued to be successful. On 20th January 1956 Mr. O. N. Lawrence, the Branch President, presented to Mr. and Mrs. Homes mementoes of their association with the Birmingham Branch and wished them success in their new venture in Southern Rhodesia. Mr. Homes' cheery good humour and pawky comment will be missed in Birmingham, but doubtless will be appreciated in Rhodesia. He goes with the good wishes of the Society.

A. M. Ballantyne

Secretary

NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Nomination of Candidates for Council

The following is an extract from the By-Laws:—

"The Twenty-one ordinary members (of the Council) shall be nominated and elected from among the members of the Society. At the date of their election at least ten shall be Fellows, and one at least shall be in each of the following classes: Associate Fellow, Associate and Graduate.

"Of the ordinary members of the Council, that number necessary to create seven vacancies shall retire annually. The retiring members shall be those with the longest service since their last election but they shall be eligible for re-election.

"Nominations of candidates for election to the Council must be received by the Secretary not later than 10th April in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination forms shall be signed by one proposer and two seconders, all of whom shall be Voters."

Nomination forms may be obtained on application to the Secretary.

Convention on "Electrical Equipment of Aircraft"

The Institution of Electrical Engineers have arranged a Convention on "Electrical Equipment of Aircraft" to be held in the Institution Lecture Theatre from the 2nd-4th May 1956, at which a number of papers will be presented. The Convention will be opened by The Rt. Hon. Reginald Maudling, M.P., Minister of Supply. The provisional programme is as follows:—

Wednesday, 2nd May 1956
Evening—Session 1—"Opening Session" (including a short introductory talk by Mr. G. R. Edwards)

Thursday, 3rd May 1956
Morning—Session 2—"Electricity in Aircraft"
Afternoon—Session 3—"Aircraft Electrical Systems"
Evening—Session 4—"Machine Equipment"

Friday, 4th May 1956
Morning—Session 5—"System Equipment"
Afternoon—Session 6—"Installation and Maintenance".

Members of the Society are welcome to attend the Convention, particularly the meetings to be held on the morning and afternoon of Thursday, 3rd May. Non-Members of the Institution should write to the Secretary of the Institution of Electrical Engineers for a registration form. The fee for the Convention is £1.

Ninth Louis Bleriot Lecture

The Ninth Louis Bleriot Lecture, entitled "A Philosophy of Aeronautical Research" will be delivered in Paris by Mr. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S., Director General of Technical Development (Air), Ministry of Supply, and President-Elect of the Royal Aeronautical Society, on the 7th March 1956 at 5 p.m. in the Salle des Anciens Elèves des Ecoles d'Arts et Métiers, 9 bis avenue d'IENA. Will members who wish to attend let the Secretary know so that further details may be sent to them.

Acknowledgments

The Council acknowledge with grateful thanks a copy of "Flying Machines" by Marshall and Greenby (1909) from Mr. R. K. Page, *Associate Fellow*. They also thank Mr Leonard Bridgman *Associate* for back numbers of the Journal.

New Year's Honours List 1956

The following members were included in the New Year Honours List:—

Knight Bachelor Professor A. G. Pugsley (*Fellow*)

Order of the British Empire

C.B.E.
- Air Vice-Marshal A. C. Kermode (*Fellow*)
- Mr. R. Graham (*Fellow*)
- Mr. R. S. Stafford (*Fellow*)

O.B.E.
- Wing Commander R. C. Fordham (*Associate Fellow*)
- Wing Commander P. H. Legg (*Associate Fellow*)
- Acting Wing Commander N. MacMillan (*Associate Fellow*)
- Mr. G. A. V. Tyson (*Associate Fellow*)

M.B.E.
- Squadron Leader M. Hermiston (*Associate Fellow*)
- Flight Lieutenant G. B. Tyler (*Graduate*)
- Mr. A. J. A. Armstrong (*Associate*)

Honours for Members

James H. Doolittle (*Fellow*) has been elected an Honorary Member of the American Society of Mechanical Engineers.

Mr. Jerome Lederer (*Associate Fellow*) has been elected a national Vice-President of the Air Mail Pioneers.

Dr. Edward P. Warner (*Honorary Fellow*) has been named a Commander of the Legion of Honour by the French Government for his outstanding work in civil aviation, particularly within the framework of I.C.A.O.

Graduates' and Students' Section—Visits

An all-day visit has been arranged to the de Havilland Engine Company's works at Leavesden, for Wednesday 22nd February 1956. A weekday has been chosen in preference to Saturday, so that the machines can be seen performing their intricate operations.

A visit has also been arranged to the Fairey Aviation Company's works at Hayes for Saturday, 17th March 1956.

Applications should be made as soon as possible to the Hon. Visits Secretary, N. K. Benson, 14 Wakering Road, Barking, Essex.

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee now invites applications for five Fellowships of an approximate value of £900 to £1,200 each for 1956. Fellowships will be awarded to selected candidates of British nationality with degree or equivalent qualifications to enable them to obtain wider experience and additional training in industrial establishments, at home or abroad, to make them more suitable for future employment in senior technical and administrative positions in British Metallurgical Industries. Each Fellowship will cover one full working year. Applicants will be required to state details of the programme they wish to carry out. Particulars and forms of application are available from: The Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1. Completed application forms are required by 1st June 1956.

Diary

LONDON

16th February

Main Lecture at Yeovil Branch.—THE FIRST HENSON AND STRINGFELLOW MEMORIAL LECTURE. Dr. A. M. Ballantyne and Captain J. L. Pritchard. Congregational Church, Princes Street, Yeovil. 7 p.m.

21st February

SECTION LECTURE.—Design of Low Landing Speed Aircraft. R. C. McIntyre. The Library, 4 Hamilton Place. 7 p.m.

28th February

SECTION LECTURE.—Use of Elementary Plasticity in Design. Anthony J. Barrett. The Library, 4 Hamilton Place. 7 p.m.

1st March

SECTION LECTURE.—Power Plants for Supersonic Flight. Dr. E. S. Moult. The Library, 4 Hamilton Place. 7 p.m.

7th March

The Ninth Louis Bleriot Lecture—in Paris. A Philosophy of Aeronautical Research. E. T. Jones, C.B., O.B.E.

15th March

MAIN LECTURE.—The High Temperature Turbo-Jet Engine. D. G. Ainley. The Institution of Civil Engineers, Gt. George Street, London, S.W.1. 6 p.m. (Tea 5.30 p.m.)

20th March

SECTION LECTURE.—Experiments on Flow Over Swept-Back Wings. P. T. Fink. The Library, 4 Hamilton Place. 7 p.m.

21st March

Main Lecture at Manchester Branch.—THE FIRST CHADWICK MEMORIAL LECTURE. The Life and Work of Roy Chadwick. H. Rogerson, M.B.E.. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

27th March

SECTION LECTURE.—The Rise of The Aircraft in Pest Control Agriculture. J. E. Harper. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

GRADUATES' AND STUDENTS' SECTION

14th February

Flight-Testing of High-Speed Aircraft. T. H. Kerr. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

22nd February

Visit to de Havilland Engine Co., Leavesden, Herts.

6th March

Annual General Meeting and Film Show. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

17th March

Visit to Fairey Aviation Company, Hayes.

BRANCHES

10th February

Brough.—Annual Dinner Dance. Jacksons Ltd., Hull.

Glasgow.—FIRST PILCHER MEMORIAL LECTURE. I. R. Liddell. Royal Technical College, Glasgow. 7.15 p.m.

13th February

Halton.—Film: Journey Together. Branch Hut, R.A.F. Halton. 6.45 p.m.

Henlow.—Annual General Meeting. Building No. 62, R.A.F. Technical College, Henlow. 7.30 p.m.

14th February

Bristol.—Aerial Photography. Charles E. Brown. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

15th February

Coventry.—Lecture. E. P. Hawthorn. The Wine Lodge. 7.30 p.m.

Halton.—Visit to Smith's Aircraft Instruments Ltd., Bishop's Cleeve, Cheltenham.

Reading and District.—Lecture and Film Show. Guided Weapons. Sqn. Ldr. R. E. W. Harland. Western Manufacturing Ltd. Canteen, Reading. 6 p.m.

16th February

Isle of Wight.—Operations of Turobo-Propeller Aircraft. P. G. Masefield. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

Yeovil.—MAIN LECTURE: First Henson and Stringfellow Memorial Lecture. Dr. A. M. Ballantyne and Captain J. L. Pritchard. Congregational Church, Princes Street, Yeovil. 7 p.m.

17th February

Birmingham.—Some Aspects of Metal Fatigue. Prof. S. J. Murphy. The Birmingham Engineering Centre, Stephenson Place, Birmingham. 7.30 p.m.

21st February

Belfast.—The New London Airport. R. F. Bulstrode. Kerr Room, Kensington Hotel, Belfast. 7 p.m.

22nd February

Southampton.—Branch Prize Papers. Institute of Education, University of Southampton. 7 p.m.

Weybridge.—Training and Research in the Field of Aircraft Production. Professor J. V. Connolly, B.E. Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6 p.m.

23rd February

Cheltenham.—The Investigation of Flutter by Flight Tests. H. G. Peacock, St. Mary's College, Cheltenham. 7.30 p.m.

27th February

Halton.—Aircrew Selection. Wing Cdr. R. W. Pye. Branch Hut, R.A.F., Halton. 6.45 p.m.

Henlow.—Underwater Television with Special Reference to the Comet Salvage Operations. G. G. MacNeill. Building No. 62, R.A.F. Technical College. 7.30 p.m.

29th February

Preston.—Lecture. R.A.F. Association, Preston. 7.30 p.m.

5th March

Derby.—Pioneering the Arctic Route. Arne Alme. Rolls-Royce Welfare Hall, Nightingale Rd., Derby. 6.15 p.m.

Glasgow.—Gas Turbine Development. S. G. Hooker. Royal Technical College, Glasgow. 7.15 p.m.

Halton.—Film. Branch Hut, R.A.F., Halton. 6.45 p.m.

6th March

Belfast.—Aircraft and Shipyard Lofting. A. C. Patrick. Reception Room, Kensington Hotel, Belfast. 7 p.m.

Boscombe Down.—Film or Discussion Evening. Lecture Hall, A. & A.E.E., Boscombe Down. 5.45 p.m.

Bristol.—Joint Meeting with Yeovil Branch: THIRD BARNWELL MEMORIAL LECTURE: Achievements and Prospects in the Field of Aircraft Engines. A. C. Lovesey, O.B.E. Main Lecture Theatre, University Engineering Laboratories, University Walk, University of Bristol. 7 p.m.

7th March

Brough.—The Production of the Vickers Viscount (illustrated). P. D. Imlach. Lecture Hall, Yorkshire Electricity Board, Ferensway, Hull. 7.30 p.m.

Chester.—Aircraft Materials and Related Problems. Dr. H. Sutton. The Grosvenor Hotel, Chester. 7.30 p.m.

8th March

Isle of Wight.—Fatigue of Metals. Major P. L. Teed. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

Yeovil.—Trends in Hovercraft Design. J. A. J. Bennett. Park School, Park Road, Yeovil. 7.30 p.m.

12th March

Halton.—Paper by a Junior Member. Branch Hut, R.A.F., Halton. 6.45 p.m.

Henlow.—The Domain of the Helicopter. R. Hafner. Building No. 62, R.A.F. Technical College. 7.30 p.m.

14th March

Southampton.—Airframe Fatigue. W. Tye, O.B.E. Institute of Education, University of Southampton. 7 p.m.

Weybridge.—The Control of Welding Processes in Aircraft Production. H. E. Dixon. (Combined Meeting with South London Branch of Institute of Welding). Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6 p.m.

16th March

Birmingham.—Aircraft Wheels and Brakes. Development and Testing. P. W. Dryland. The Goodyear Tyre & Rubber Co. Ltd., Wolverhampton. 7.30 p.m.

19th March

Halton.—Aerial Surveys. H. G. Dawe. Branch Hut, R.A.F., Halton. 6.45 p.m.

20th March

Belfast.—Radio Aids to Navigation. H. H. Capes. Kerr Room, Kensington Hotel, Belfast. 7 p.m.

21st March

Chester.—Joint Meeting with Stanlow Branch of Institute of Petroleum. Fuels and Lubricants for Jet Engines. K. C. Hunt. The Grosvenor Hotel, Chester. 7.30 p.m.

Gloucester.—Lecture. The Wheatstone Hall, Brunswick Road, Gloucester. 7.30 p.m.

Manchester.—MAIN LECTURE. The First Chadwick Memorial Lecture: The Life and Work of Roy Chadwick. H. Rogerson, M.B.E. Reynolds Hall, College of Technology, Manchester. 7.30 p.m.

Preston.—The Advantages and Disadvantages of Swept Wings. Dr. D. Küchemann. Queen's Hotel, Lytham. 7.30 p.m.

Reading and District.—Some Maintenance Aspects of Viscount Operation. E. R. Major. Western Manufacturing Ltd. Canteen, Reading. 6 p.m.

22nd March

Isle of Wight.—Development of Gas Turbine Engines. Dr. S. G. Hooker, O.B.E. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

NEWS OF MEMBERS

R. BENSTEAD (*Graduate*) has left Avro Aircraft, Malton, Ontario, to take up a post with Convair, San Diego, California as a Design Engineer.

N. O. BRAND (*Associate Fellow*) has left the General Electric Research Laboratories at Stanmore and is now a Designer (Aircraft) with Avro Canada Ltd., at Malton.

H. CAPLAN (*Associate Fellow*) has been appointed Assistant Chief Technical Officer, Air Safety and Survey Division of British Aviation Insurance Company.

E. J. CATCHPOLE (*Associate Fellow*) formerly with Vickers-Armstrongs has joined Aero Research Limited, Duxford, Cambridge as Personal Assistant to Dr. N. A. de Bruyne.

J. L. EDWARDS (*Associate Fellow*) formerly Chief Combustion Research Engineer with the de Havilland Engine Co., is now Assistant Chief Engineer.

Group Capt. J. A. Kent (*Associate Fellow*) formerly C.O. of R.A.F. Station, Tangmere has been appointed Senior Officer in charge of Administration at Headquarters, No. 12 Group Fighter Command.

D. C. KOHLI (*Graduate*) has joined the Structural Dept. of Rotol Ltd. as a Technical Assistant (not Rolls-Royce Ltd. as stated in December).

Captain M. LUBY (*Fellow*) has been appointed Vice-Chairman of the Board of Rotax Ltd.

J. J. MOLINS (*Associate Fellow*), Chief Designer of Microcell Ltd., has been appointed an Executive Director of the Company.

Group Capt. J. A. NEWTON (*Associate*) formerly Senior Officer Accident Investigation, I.C.A.O. has been appointed Chief of the Flight Branch, I.C.A.O.

Air Vice-Marshal W. A. Opie, C.B., C.B.E. (*Associate Fellow*), formerly Assistant Controller of Aircraft, has been appointed Principal Director of Aircraft Research and Development (Royal Air Force).

W. A. PARR (*Associate*) has been elected President of the Institute of Executive Engineers and Officers.

C. P. S. POPKIN (*Associate Fellow*) formerly Assistant Resident Technical Officer at A. V. Roe & Co. has been appointed as an Engineer III Ministry of Supply to D.G.W.T.D./G.W.S.1 (b).

A. A. ROSE (*Associate Fellow*) formerly with Avro Aircraft of Toronto has taken up a post as Design Engineer with Convair in San Diego.

Pilot Officer E. J. SCANES (*Graduate*) took up a Short Service Commission in the R.A.F. as an Engineer Officer.

J. HANFORD STEVENS (*Associate Fellow*) has joined the Firth Cleveland Group as Managing Director of their Australian Subsidiary Aerocessories, at Ballarat, Victoria.

Wing Cdr. C. V. G. USHER (*Associate Fellow*) has just taken up an appointment on the directing Staff of R.A.F. Staff College, Bracknell, Berks.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

John Alexander Anderson (*from Graduate*)
Geoffrey Edward Beck
Alan Francis Britton
Charles Basil Budd (*from Graduate*)
Brian Robert Carter (*from Graduate*)
Ernest Baker Dove (*from Associate*)
Robert William Everall (*from Associate*)
Dennis Farrell
William Henry Johnson (*from Graduate*)
John Alfred Hawkings
Edward James Gwynn Hill
Peter Michael Lavelle
Charles Geoffrey Longford
Gordon Eric Monger (*from Graduate*)
Douglas Moore (*from Graduate*)
Alan Lancelot Oliver
John Arthur Stephen Outhwaite
Clement Barry Redgate (*from Graduate*)
John Rex (*from Graduate*)
Kenneth Mervyn Smith
Maurice Dudley Smith (*from Associate*)
Antony Geoffrey Strutt
Lawrence Randall Symons
Norman Ralph Taylor (*from Associate*)
Alan William Thompson (*from Graduate*)
Harry Percival Thornton
Donald George Titford
James William Wisdom

Associates

Roy Bowden
Donald Drayton
Charles Edward James Eather
Harold William Ellis
Thomas George Horton
Eric Hustwayte
Leonard Horace Lambert
Hugh Derrick Thomas Owens (*from Student*)
Francis Pickett
Peter Henry Reed (*from Student*)

Graduates

Leonard David Allen
Berry John Belcher
Charles John Cooke
Peter Henry Dove
Peter George Edgington (*from Student*)
John Ellis
Michael Ennis
Manjeshwar Gurudutt
Halsey Charles Hall
Edgar Thomas Harris (*from Student*)
Ronald Michael Leckenby
Joseph Brian Menin (*from Student*)
Stewart Crichton Miller
Bryan Edward Neave (*from Student*)
David Edward Rayner (*from Student*)
Sunder Lal Relan
Edwin Donald Stride
Michael Edwin Thomas (*from Student*)

Students

Brian Peter Broadley
John Duncan Brown
Keith Burchell
Michael David Clarke
Owen William Nott Cock
Brian John Edwards
David Geoffrey Edwards
Julian Thomas Everest
David Fry
Neil Harding
Francis George Jones
Perincheri Kunhiraman
Thomas Markham
Graham Montague Morgan
Jerzy Tytus Mucho
Eliahov Nissim
George Charles Pearson
John Alan Porter
Vellara Verghese Samuel
George Alfred Brian Seth
Michael Joseph Sheehan
James Emerton Smith
Pamela Mary Smith
John Malcolm Tagg
Donald Peter Timperley
Desmond Arthur Yow

ANNUAL SUBSCRIPTIONS

Members are reminded that their annual subscriptions became due on 1st January 1956. The rates are:—

	HOME £ s. d.	ABROAD £ s. d.
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*Associates	3 3 0	3 3 0
Graduates (aged under 26)	2 2 0	2 2 0
Graduates (aged 26 and over)	2 12 6	2 12 6
Students (aged under 21)	1 1 0	1 1 0
Students (aged 21 and over)	1 11 6	1 11 6
Companions	3 3 0	3 3 0
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* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the JOURNAL; in this case his subscription will be reduced to £2 2s. 0d.

When sending remittances for subscription, members should state their names clearly and give their addresses and grades of membership.

The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 60 FEBRUARY 1956 NUMBER 542

ALFRED GILMER LAMPLUGH, *Fellow*

19th October 1895 - 15th December 1955

THE DEATH OF CAPTAIN A. G. LAMPLUGH on 15th December 1955, at only sixty years of age is a grievous blow to aviation and one that I personally feel most deeply, for our activities in the aeronautical world brought us together on frequent occasions over a period of many years.

Captain Alfred Gilmer Lamplugh, C.B.E., F.R.Ae.S., M.I.Ae.S., M.C.A.I., F.R.G.S., had been Underwriter and Principal Surveyor of The British Aviation Insurance Co. Ltd. since its formation until his retirement and election to its board of directors in September last.

He was educated at King Edward's School and Queen's College, Birmingham. His interests were technical rather than scholastic, however, and he served an apprenticeship with a firm of motor engineers. In 1913 he learnt to fly and obtained one of the very early "B" licences.

The Great War came and he went into the army, to be seconded later to the R.F.C. He served in that corps and in the R.A.F. until 1919.

It was abroad, in China, that he gained his first experience of insurance. Then, home once more, he became Underwriter to the British Aviation Insurance Group, later the British Aviation Insurance Co. Ltd., and was introduced to aviation insurance, this group in those days being the only body to undertake such work.

His interest in almost every aspect of things aeronautical was enormous and far beyond a merely professional one. This interest—and his great abilities—were reflected in the number of positions, mainly honorary in nature, which he filled with success and in many cases for long periods.

He was a member of the Committee of the Royal Aero Club for nearly thirty years; a member of the Council of the Air Registration Board since its inception; Warden and first Deputy Master of the Guild of Air Pilots; an honorary member of the British Airline Pilots' Association; a member of the International Union of Aviation Insurers; Chairman of the Aviation Insurance Offices Association; and President of the London Gliding Club. In 1943 he was Chairman of the Independent Committee on the Future of Civil Aviation.

He did much for flying, both in these capacities and in other ways, not least by his services in the field of insurance. It was in recognition of this that he was appointed a Companion of the Order of the British Empire.

Captain A. G. Lamplugh

"Lamps" made it his business and his pleasure to be at the heart of aeronautical activities, not only getting to know people, but getting to know them well. He was a familiar figure at aviation gatherings of every sort since the early 'twenties and will be missed by very many of us indeed.

SIR FREDERICK HANDLEY PAGE

J. Laurence Pritchard writes:

I have a great affection for "Lamps," and I am glad to be able to express it in the JOURNAL of the Society, of which he was such a good friend.

On September 14, last year, he wrote to me, in reply to a letter of mine about a project of his, "It would be nice to have some stabilizing influence like yours in the show and it was kind of you to write. Your interest has bucked me up a lot."

"Lamps" must have known that his chance of carrying out his idea was very small indeed, but his magnificent courage would never allow him not to try,

whatever the odds were. I shall always be glad that I was the first to reply to his suggestion, for he was the first to listen to any suggestion of mine when he was on the Council of the Society, and its Honorary Treasurer.

"Lamps" joined the Society in 1924, and became an Associate Fellow two years later. In 1929 he was made a Fellow.

On the Council, to which he was first elected in 1933, he was a tower of strength with his direct comments, which were always listened to, and generally agreed upon. It was a tribute to his practical and sane outlook that the year he was elected to the Council, he was asked to serve on the Finance Committee, upon which he served until 1947.

He was Honorary Treasurer in those difficult years 1941-46 when Councils and Committees were not able to give close consideration to the affairs of the Society, and I wanted what help I could get.

"Lamps" often dropped in casually in those days, talked about any difficulties I may have had, and just as casually went out, saying, "All right, chaps, it'll be done." It was. Few appreciated how quietly he kept up others' morale, how shrewdly he summed up all those with whom he came in contact.

During the War he once gave me a lift in his car into the West Country. Those were the days when all sign posts had been obliterated, post office and village signs blotted out, and driving was difficult. Yet he drove with great assurance, often on minor roads, while we talked of everybody and everything. In his car he had a small portable wireless set, given him in New York, so that he could hear the news wherever he happened to be. Fixed below the dashboard was an aeroplane compass.

"That's how I find my way," he replied cheerily, when I was complimenting him on his knowledge of all the by-roads.

When the offices of the Guild of Air Pilots were destroyed I agreed to find room for their staff at 4 Hamilton Place. "Lamps" was one of the Wardens of the Guild and often came in to see how things were going. One day a bomb dropped in Hyde Park and blew in some of the office windows. I had given very definite orders that the moment the sirens sounded their warning all curtains were to be drawn and staff were to keep away from windows.

I went round the building, and as I walked up the stairs to the Guild of Air Pilots' room Lamplugh followed me. He had dashed round to see how things were. One of the girls was sitting in front of her typewriter by a window, the blind not drawn. For disobeying the orders upon which her life might have depended she got no praise but was told sharply where to sit in future. I expected "Lamps" to say something to me about the way I spoke to someone not on the Society's staff. All he said was, as we walked away, "Good show, chaps."

I believe that when someone tries to assess the personalties of these early years of aviation, that of Alfred Gilmer Lamplugh will rank very highly indeed, for he had courage and vision when both were required in full measure.

The Skid-Resisting Properties of Wet Surfaces at High Speeds:

Exploratory Measurements with a Small Braking Force Trailer

by

C. G. GILES, B.Sc., A.Inst.P. and F. T. W. LANDER

(*Road Research Laboratory, Department of Scientific and Industrial Research*)

1. Introduction

The effectiveness of any braking system is ultimately limited by the point at which the wheels lock and slide over the surface on which the stop is being made. When surfaces are clean and dry the adhesion with a rubber tyre is high enough to meet most requirements of braking without risk of skidding. In wet, or in icy conditions, however, adhesion may be reduced to such an extent that, even with efficient brakes, stopping distances are greatly increased and dangerous conditions can arise. Under wet conditions there are special difficulties. Different surfaces may have very different skid-resisting properties and, in addition, when surfaces are wet, the adhesion with a tyre depends on speed, generally diminishing as speed is raised.

It follows that in considering such problems as the landing-distance requirements for aircraft, or requirements for runway lengths, it is important to have information on the range of frictional coefficients which may arise on different surfaces in wet conditions, and on the way in which these coefficients may vary with speed, at least up to speeds comparable with the landing speeds of modern aircraft.

Hitherto, although many measurements of the frictional properties of wet surfaces have been made, the available data are mainly for speeds of the order of 30 m.p.h.; only in a few of these measurements have speeds as high as 60 m.p.h been obtained.

The increased importance of braking in the operation of modern jet aircraft, and the increasing number of road vehicles able to travel at speeds of the order of 100 m.p.h. have now made it more than ever necessary to extend the range of speeds over which data on the skid-resisting properties of wet surfaces are available. This paper gives details of a programme of exploratory tests, carried out by the Road Research Laboratory on behalf of the Ministry of Transport and Civil Aviation, in which measurements of frictional coefficients were made on a number of wet runway surfaces at speeds up to just over 100 m.p.h.

The tests were made with limited objectives, the aim being to explore the possibilities of a simple measuring technique, and to investigate, for a particular size of tyre and wheel load, the way in which skidding resistance could vary with speed on some typical wet surfaces. Measurements were made with smooth tyres and with tyres having a simple tread pattern and, in addition, the tests included a few measurements at the higher speeds on a surface that was dry. This paper gives details of the tests and the results obtained, with a description of the apparatus and the technique of testing, and details of the surfaces upon which the measurements were made. The tests showed that the methods employed were successful in achieving the objects of the investigation; additional details, which it is thought may assist other interested organisations to make similar observations, are given in the Appendix.

Received 9th November 1955

2. Details of Tests

2.1. METHOD OF MEASUREMENT

All the measurements of skidding resistance described in this paper were made with the Road Research Laboratory's experimental trailer apparatus (Fig. 1). Details of the apparatus are given in the Appendix; essentially it consists of a small, light single-wheel trailer, which in these tests was towed at the required speeds by an XK120 Jaguar car which had a towing bracket fitted in place of the rear bumper.

A representative section of each runway some 200 yd. in length was selected, and this was maintained in a thoroughly wet condition with the aid of a water tanker or fire tender equipped with a suitable spray. (Measurements made during the tests showed that this was achieved by spraying an initial thickness of about 0·060 in. of water on to the dry surface and replenishing this at frequent intervals with a spray equivalent to a film 0·020 in. thick). Runs were then made with the trailer over this section at various speeds up to the maximum speed that could be attained, and on each run the brake on the trailer was so applied as to lock the wheel for a period of about two or three seconds on the wetted length of the runway.

Figure 2 shows the recording apparatus employed; this was connected to the trailer wheel and was adapted to fit in place of the passenger's seat in the towing car.

FIGURE 1. The braking force trailer, attached to the high speed car, used in the tests.

The apparatus gives records on a moving chart of the braking force exerted by the surface on the locked trailer wheel, together with time marks from a $\frac{1}{2}$-second clock, and signals derived from a contact in the hub of the trailer wheel which was made and broken once for every revolution of the wheel.* Thus, for each application of the trailer brake a record was obtained showing the variation of braking force with time, together with signals showing the speed of rotation of the wheel immediately before, and after, each operation of the brake, and confirming that on each application the test wheel was completely locked. Braking-force coefficients were deduced from each recording of braking force simply by finding the average braking force while the wheel was locked, and dividing this by the static load on the test wheel. The trailer was specially designed to make this a valid procedure, and details of its design and of an experiment to check this assumption under the conditions of test are given in the Appendix.

Using the technique described, sufficient runs were made in each of the tests to give at least three separate measurements of braking-force coefficient at each interval of 10 m.p.h. up to the highest speed that could be attained. Up to 70 m.p.h., runs were made in both directions and the speed of test for each successive run was arranged in a random manner. Above this speed the runs were all made in the direction favouring the greater speeds (as determined by the direction of the prevailing wind, and any gradients) and the speed of test was increased by steps of 10 m.p.h. until the maximum speed possible was reached. Further readings at various speeds between 20 and 70 m.p.h. were, however, also made on the return run following each of these tests at the higher speeds.

In this way tests were carried out on seven representative runways over a full range of speeds, using a smooth-tread tyre and a tyre with a simple tread pattern. At the conclusion of the main programme a few measurements were also made using a patterned tyre on a dry runway, at speeds between 50 and 100 m.p.h.

*To facilitate recording in the tests at higher speeds, a "counting down" circuit was used between the contacts in the hub and the recording pen.

2.2. DETAILS OF TRAILER

In this section attention is given only to those characteristics which must be borne in mind in considering the wider applications of the results, or which are considered of special importance in contributing to the successful completion of the tests. The trailer was designed with the primary object of producing a small and light test apparatus which could be fitted to most cars with the minimum of modification, and which would have the smallest possible effect on their stability, even when testing on dangerously slippery surfaces. It is these characteristics of the trailer which made possible the extension of its use to the present series of high speed tests.

To meet the requirements, a 16×4 in. tyre was selected as the basis of design: this size probably resembles more than anything else, the smallest size of tyre used by aircraft. With this size of tyre, the wheel load, which was 317 lb., was so chosen in relation to the unsprung weight of the tyre and wheel, as to ensure a suspension with good characteristics. With this wheel load, and the use of springs of rubber cord, damped by means of a hydraulic shock absorber, excellent suspension characteristics were secured and the trailer was very stable in operation, even at the maximum speeds which were obtained.

To ensure its quick operation, a form of disc brake was used on the trailer wheel and this was arranged so that it could be brought into action by a vacuum servo-system, controlled by the driver using the push button shown in Fig. 2. This rapid operation of the brake ensured that there was no trouble from over-heating or brake fade, even on the very high-speed runs.

Braking forces were measured by arranging that a torque arm, attached to the brake, acted against a hydraulic pressure capsule, and the pressure in this was transmitted, through steel capilliary tubing and a damping valve, to a Bourdon tube, which operated the

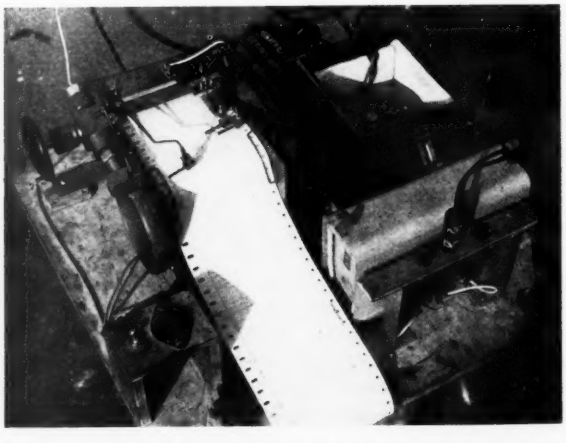


FIGURE 2. Recording apparatus adapted to fit in place of passenger's seat of towing car.

recording pen. The calibration of the apparatus was checked at frequent intervals by applying known braking forces to the trailer wheel.

In addition to applying the brake, the servo system also operated a clamp, to prevent the trailer from swinging about the towing point while the wheel was locked. Preliminary tests showed that this was an indispensable requirement. Without it, the trailer tends to swing to one side while the brake is applied, and then, as soon as the brake is released with the trailer inclined, a violent oscillation of the car and trailer from side to side is liable to be set up. The expedient of clamping the trailer in position while the brake is on overcomes these difficulties, but in high-speed testing it places a stringent requirement on the characteristics of the towing car. When the brake is applied the trailer represents, in effect, an additional heavy weight overhung by a distance of some three feet behind the rear of the car. Such an arrangement is very liable to promote "oversteer" or, in other words, the car will tend to swerve violently to one side or the other when testing at high speeds, and so it is important that the test car be one with a high degree of stability. To establish that this was in fact so, preliminary tests were made with the trailer and the chosen test car in which the speed was increased step by step up to the highest speeds likely to be employed in the tests.

The requirement for stability at high speeds is an important one in considering any possible future extension of the present tests. From some points of view it would, of course, be desirable to make further high speed tests in which larger tyres and wheel loads were employed; it is difficult to see a way in which this could be done on the lines of the present experiments, however, without a greatly increased risk of instability of the test vehicle and trailer at the higher speeds.

It follows, therefore, that the measurements have been made with a relatively small wheel load, tyre size and inflation pressure. Over the range that has been covered, tests have shown that these factors generally have only a small effect upon values of the coefficient when a rubber tyre skids on wet surfaces. If anything, because of their effects, it is to be expected that values of coefficient obtained in the present tests will be slightly lower than those given under similar circumstances by the larger, and more heavily laden tyres of aircraft.

2.3. DETAILS OF TEST TYRES

Tyres as small as 16×4 in. are not generally designed for running at speeds of the order of 100 m.p.h. It was therefore necessary to give special attention to the tyres which were used for the tests, and for this purpose a number of tyres designed to stand up to the high rotational speeds which the tests involved were specially made by the Firestone Tyre and Rubber Company. These tyres were constructed of normal aircraft tread rubber stock and had 6-ply cords of rayon. Photographs of these special tyres are shown in Fig. 3.

Originally the tyres were quite smooth; tests have shown, however, that on some types of wet surface a tread pattern can have an important effect upon skidding resistance. It is reasonable to suppose that the magnitude of the difference between the results of tests made with a smooth tyre, and with a patterned tyre, on the same surface, may give some indication of the importance of other possible changes in contact conditions such as large differences in wheel load, size of contact patch and so on. It was for these reasons that it was thought desirable to test tyres with an effective tread pattern, as well as smooth tyres.

As a first step in developing a suitable pattern for use in the tests, four longitudinal grooves were cut in the surface of some of the tyres; these can be seen in Fig. 3. Tests with tyres modified in this way showed that, while there was some improvement in skidding resistance on those sections of the Laboratory's test track on which a tread pattern is known to be beneficial, the improvement was not as large as that given in similar circumstances by the modern types of tyre tread pattern. Tests by the Laboratory have indicated that, if a print is taken showing the contact patch of a tyre under load on a smooth surface, the ratio

$$\frac{\text{Perimeter of contact patch}}{\sqrt{\text{Area of contact patch}}}$$

gives an empirical guide to the effectiveness of the pattern. Additional transverse cuts were therefore added at regular intervals to the pattern of longitudinal ribs, as Fig. 3 shows, to obtain a value of this ratio comparable with that of modern patterns. Tests on the Laboratory's skidding track confirmed that, with this addition, the effectiveness of the patterns on the experimental tyres on smooth wet surfaces was of the same order as that of the patterns which are used on the tyres of cars.

Prints showing the dimensions of the contact patches obtained with the test tyres under load on a smooth surface, are given in Fig. 4. As far as tyres are concerned, the conditions of test employed in the present experiments may be summarised as follows:—

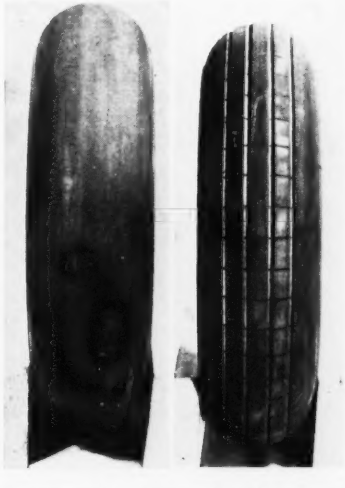


FIGURE 3. Photographs of smooth and patterned tyres used in the tests.

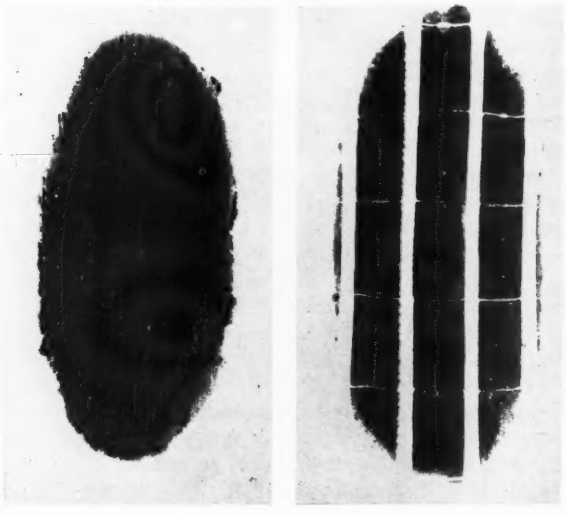


FIGURE 4. Contact patches on the test tyres (half actual size).

Tyres: specially made 4·00 × 16 in. 6-ply tyres with rayon cords.

Wheel load: 317 lb.

Inflation pressure: 20 lb./in.²

Hardness of tread rubber: 65° (Dunlop rubber scale).

Modulus of tyre deflection: 20 per cent.

Area of contact patch: 8·35 in.² (smooth tyre)
6·75 in.² (patterned tyre)

Perimeter of contact patch: 11·3 in. (smooth tyre)
47·3 in. (patterned tyre)

$\frac{\text{Perimeter}}{\sqrt{\text{Area}}}$: 3·9 (smooth tyre)
16·3 (patterned tyre)

3. Details of Test Surfaces

Over the range of speeds covered by previous tests it has been established that the texture of a surface is the essential property which determines its skidding resistance in wet conditions. In general, the harsher a surface to the touch, the more skid-resistant it is likely to be when wet. The texture of any surface is, of course, determined by its composition, by the method of laying and finishing, and by the combined effects of the traffic and weather to which it has been subjected. It has been established, however, that if suitable steps are taken, a harsh, non-skid texture can be obtained with all the modern forms of construction. In this exploratory investigation therefore the aim was to study the skid-resisting properties at high speeds of some representative types of surface texture which may be found on runways, and not to determine the relative merits of the different materials used and the methods of construction by which these different textures were obtained. To determine the relative merits of these it would be necessary to test more examples of each type than could be covered in the present tests. The runways chosen for the investigation were, therefore, selected as covering a representative range of surface textures, without regard to whether or not they were in any sense typical of the performance of the kind of surfacing which may have been employed in their construction.

In planning the tests, details were obtained of the surfacings of some 20 runways on which it was possible for the measurements to be made. Runways of sufficient length were inspected, and on the basis of these inspections seven runways covering the desired range of surface textures were selected. In making this final selection special weight was first given to certain runways known to be used in the performance testing of aircraft. Details of the various runways on which tests

TABLE I

DETAILS OF RUNWAYS SELECTED FOR TEST

Runway	*Surface texture shown in Fig.*	*Type of surfacing*	*Notes*
A	5	Machine-laid bitumen macadam	Uniform and very harsh surface texture
B	6	Bitumen macadam with gravel aggregate	This runway had a more coarse-textured appearance than is usual for runways
C	7	Machine-laid bitumen macadam	Rather more coarse-textured, but less harsh than runway A
D	8	Machine-laid concrete surface	Surface left as finished
E	9	Older concrete surface	Surface of fairly smooth appearance which had at some time been covered with a film of tar or bitumen
F	10	Machine-laid concrete surface	Surface variable, finished by brooming to produce a harsher texture, but sprayed with tar or bitumen which had left it fairly smooth
G	11	Surface-dressed concrete	Extremely variable as Figs. show, and very smooth in places. On this runway, which was the longest available, test speeds were limited by the indifferent riding quality of the surface

were made are summarised in Table 1; close-up photographs showing their surface texture are given in Figs. 5 to 11.

In the course of examining the various runways it appeared that, by comparison with road surfaces, the effect of traffic on the surface texture was comparatively small and the effects of weather appeared to be much more important. This should favour the attainment of good non-skid properties on runways. It was noticed that even on the busiest runways seen, rubber deposited during the moment of touch down was not liable to have a serious effect by making the surface slippery in wet weather.

4. Results

4.1. TEST RECORDS AND THEIR EVALUATION

Figure 12 shows two typical records obtained in the course of the tests. When the brake is applied, the record of braking force first shows an initial kick representing the sudden stopping of the wheel, and then, after the wheel has been locked, the record fluctuates about a mean value of braking force indicating the adhesion between the locked wheel and the surface under the conditions of the test. For each record, the value of this mean braking force was determined and the speed at which the test was made was deduced from the traces of the time and wheel revolution pens.

Variations in braking force such as those shown in Fig. 12, which occur while the wheel is locked, have two principal causes. First, they arise from variation in the skidding resistance of the surface from point to point in the path of the test wheel, and secondly, as a consequence of the inevitable fluctuations in the normal force between tyre and surface as the test wheel follows the contours of the surface. Compared with the time for which the brake is applied, the latter are comparatively rapid and, as was confirmed by experiment, the static wheel load can therefore be taken as the effective normal force on the test tyre. For each test, a value of braking-force coefficient indicating the skid-resisting properties of tyre and surface can therefore be deduced from the mean value of braking force simply by dividing by the static wheel load.

Attention has been drawn to the marked variations in surface texture on some of the runways that were tested. Variations in texture which cause differences in skid resistance in different parts of surfaces are found to occur, however, even on surfaces with quite a uniform appearance; for this reason values of coefficient measured in repeated tests on surfaces may have standard errors of up to about 0·05. In summarising the results of tests, therefore, individual values of coefficient and speed are first plotted on a coefficient/speed graph, and the values of coefficient representing the performance of the surface at intervals of speed of 10 m.p.h. are read off from a mean line drawn through the plotted points.

4.2. SUMMARY OF RESULTS

Coefficient/speed curves representing the results are given in Fig. 13. The skidding distance in feet from

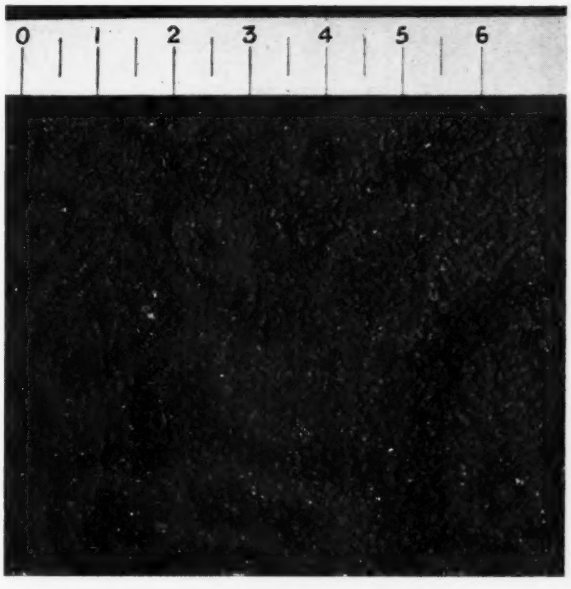


FIGURE 5. Runway A (0·45 full size).

100 m.p.h. given by the side of each curve was calculated as a "figure of merit" from the coefficient/speed curves on the assumption that all wheels of the vehicle were locked, and the friction between tyres and surface provided the only decelerating force.

From the results of the tests it is evident that at least up to speeds of the order of 100 m.p.h., the skid-resisting properties of surfaces in wet conditions follow the same trends, and exhibit the same characteristics as are found in the results of previous measurements at lower speeds. The main features of the results of the tests may be summarised as follows:—

(*a*) On all the surfaces, braking-force coefficients measured with a locked wheel diminish as speed is raised, at least up to speeds of 100 m.p.h.

(*b*) There are marked differences in the results given by the different surfaces under the same conditions of test. With a smooth tyre, for example, the surface with the harshest texture gave a coefficient of the order of 0·4 at 100 m.p.h., while on another surface at this speed the coefficient was only of the order of 0·1. For all the surfaces tested, the mean coefficient at 100 m.p.h. with a smooth tyre was 0·24. "Skidding distances" from 100 m.p.h. calculated from the results of tests on the different wet surfaces range from about 680 to 1,600 ft. with a smooth tyre.

(*c*) As has been found in previous tests at lower speeds* the effectiveness of the tyre tread pattern in improving skidding resistance on the different surfaces is very dependent upon their

*GRIME, G. and GILES, C. G. *Proceedings of the Institution of Mechanical Engineers*, Automobile Division, 1954-55 No. (1), pp. 19-30.

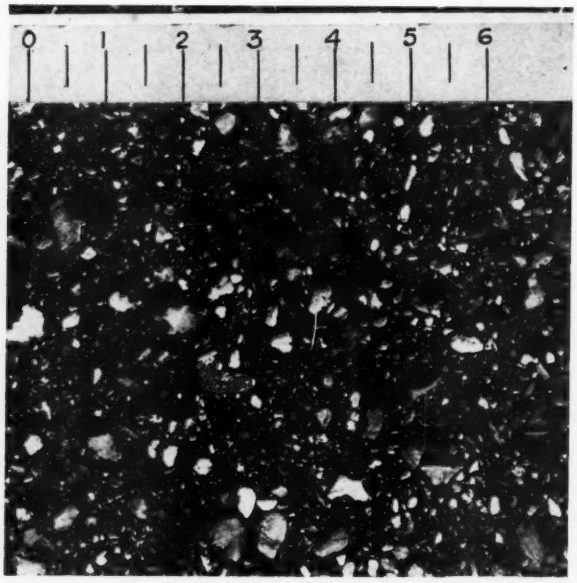


FIGURE 6. Runway B (0·45 full size).

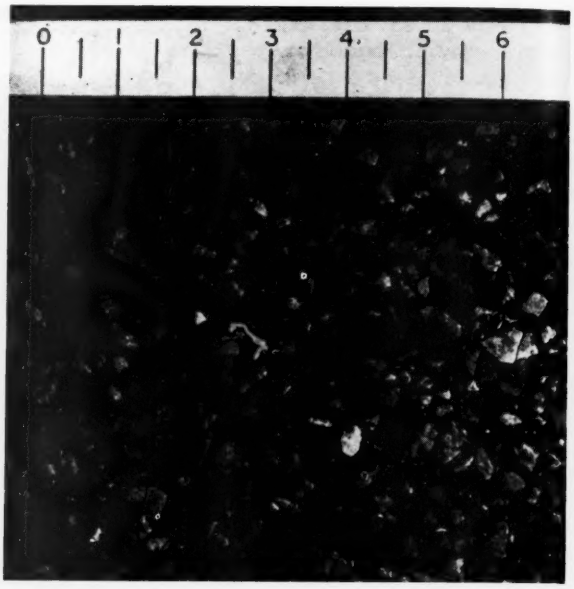


FIGURE 7. Runway C (0·45 full size).

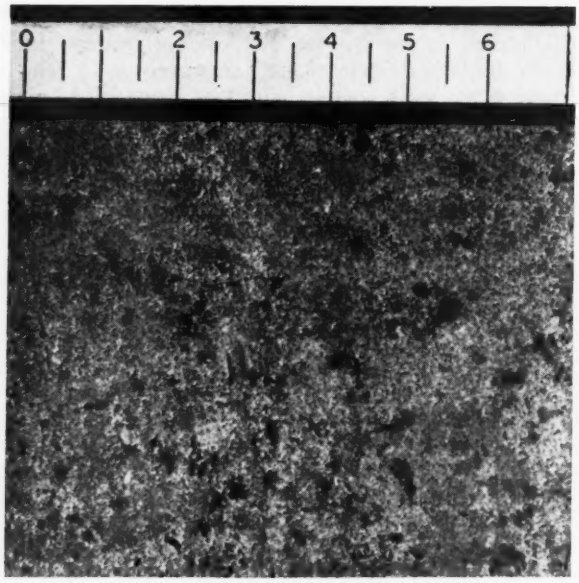


FIGURE 8. Runway D (0·45 full size).

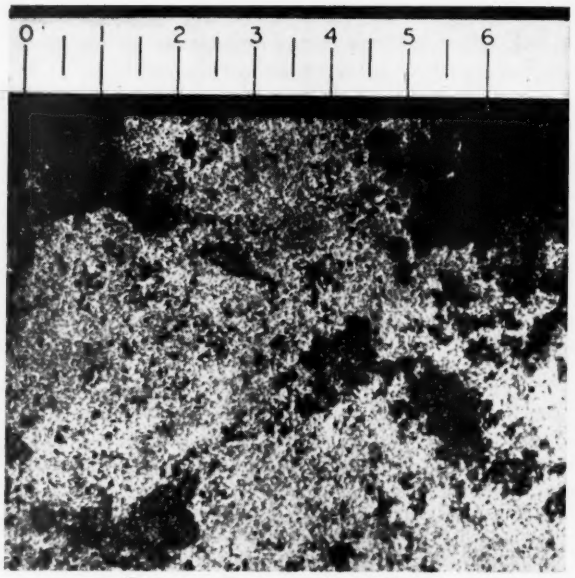


FIGURE 9. Runway E (0·45 full size).

surface texture. In general, however, especially as on runways E and F of the present tests, it is clear that on wet runways the use of tyres with an effective tread pattern produced a useful increase in adhesion. With the patterned tyre in use, coefficients on the different runways ranged from 0·2 to 0·5 at 100 m.p.h., with a mean of 0·31.

(*d*) From the results of the tests it is evident that there is no simple, or single law, relating values of coefficient and speed, which can be used to represent results on all the surfaces. As has been found in previous tests at low speeds, each surface gives its own particular curves and attempts to analyse the results in various ways to evolve some general relation between coefficient and speed were unsuccessful. It was found, for example, that curves fitted to the results for speeds up to 50 m.p.h. could not in general be used to represent the experimental results for higher speeds. Thus, it appears that there is no certain way by which results obtained in tests made at, say, 50 m.p.h can be extrapolated to give reliable values of coefficient at 100 m.p.h. Such values can only be determined by measurement.

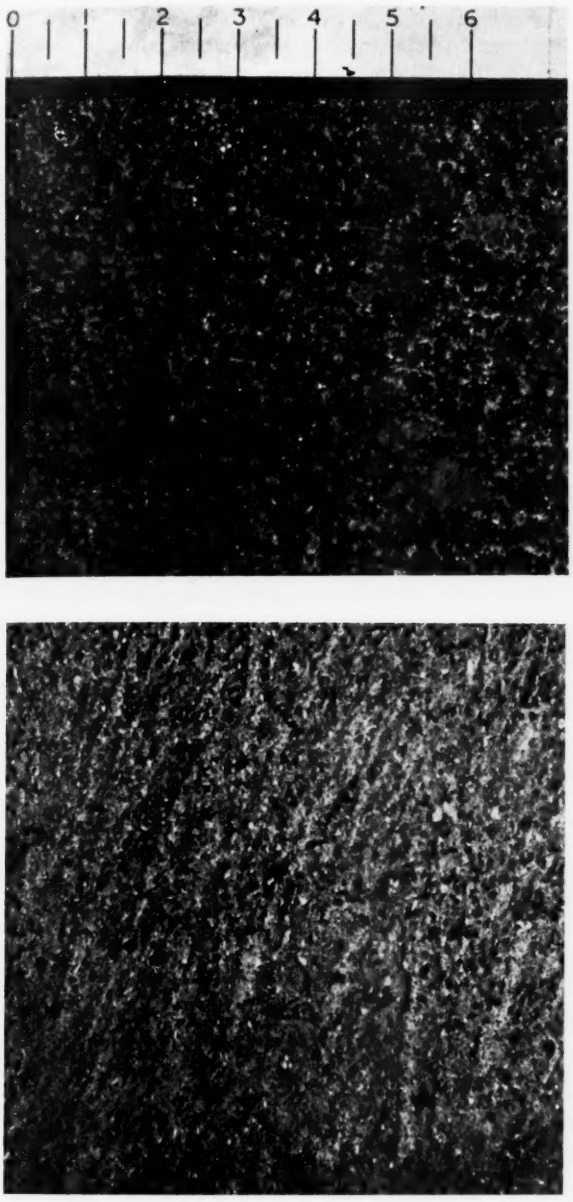


FIGURE 10. Runway F (0·45 full size).
Photographs show the range of surface texture on this runway.

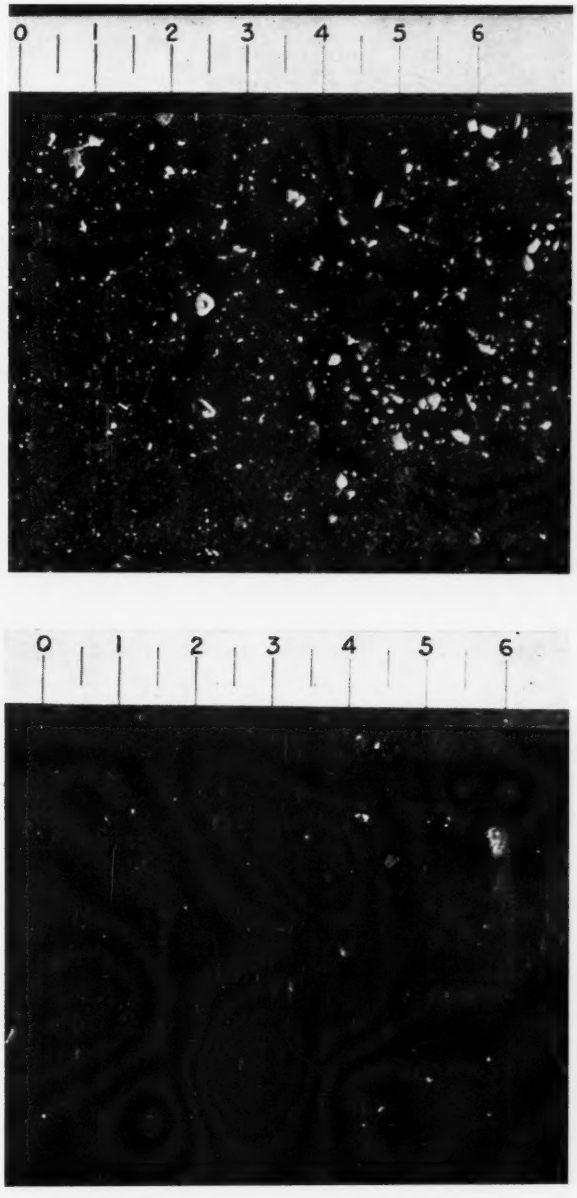


FIGURE 11. Runway G (0·45 full size).
Photographs show the range of surface texture on this runway.

(*e*) From the photographs given in Fig. 11 it will be evident that in places at least, the surface of runway G was not one which would be expected to have good skid-resisting properties. It is interesting to note that runways E and F which gave the next lowest results, were both of concrete which had at some time been sprayed with a film of tar or bitumen. Such a procedure, while it may be an advantage in facilitating "curing," is obviously undesirable in the interests of obtaining good skid-resisting properties in wet conditions.

4.3. TEST RESULTS AT HIGH SPEED ON A DRY RUNWAY

At the conclusion of the main programme of tests, six tests were made on runway D at speeds between 55 and 100 m.p.h. when the surface was dry. The results of these tests emphasise the important effect which the presence of a liquid film has upon skid-resisting properties of surfaces. In the dry tests the coefficients ranged from 0·73 to 0·82 about a mean value of 0·76, and in contrast to the results on wet surfaces, it was the test at 100 m.p.h. which gave the highest result. Thus in this respect also, the results of the present tests confirm the indications of all earlier tests at lower speeds, in showing

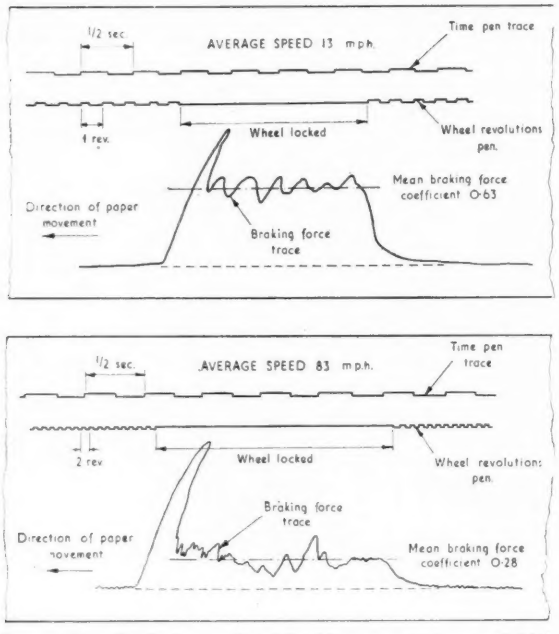


FIGURE 12. Typical records of braking tests at low and high speeds.

that when surfaces are dry, coefficients are of the order of 0·7 to 0·8 and speed has little or no effect upon the values of the coefficient. In the present investigation the results have additional value in that they make it clear that the relatively low values of coefficient obtained on all the wet surfaces at high speeds are a direct consequence of the presence of the water film, and do not arise from any peculiarity of the test apparatus or recording gear employed in the tests.

4.4. TYRE WEAR

In spite of the short duration of each test, severe tyre damage was caused in the tests at 100 m.p.h. on the dry surface, as can be seen in Fig. 14. The damage is so extensive that if any further work were to be envisaged on dry surfaces at high speeds, it would clearly be necessary to use a fresh tyre for each individual measurement.

In the wet tests, tyre wear was very different and over most of the speed range the tyres sustained very little damage as a result of being locked for a few seconds on a wet surface. An unexpected form of tyre damage appeared, however, in several of the tests made on wet surfaces at speeds above 80 m.p.h. Figure 15 shows photographs of two tyres which exhibit this peculiar type of wear. From an examination of the tyres after the tests it appears that the rubber immediately below the surface layer of the tyre has become softened by heating, leaving the surface layer of rubber unchanged, and partly torn away from the underlying rubber. The cause of any such heating producing this effect at high speeds where the coefficients are lowest is not obvious, however, and from microscopic examination of portions of rubber cut from the tyres it appeared that whatever the effect had been, it was confined to the tread rubber in the immediate vicinity of the contact patch when the wheel was locked. Elsewhere the tread rubber appeared to be unaffected. Whatever its cause, it is interesting to note that tyre wear of this type appears to be characteristic of a tyre that has skidded on a wet surface at a speed in excess of about 80 m.p.h.

5. Discussion of Results

5.1. SKID RESISTANCE IN WET CONDITIONS

In general it appears from the results of the tests that the same factors influence the skid-resisting properties of surfaces in wet conditions at the higher speeds, as are operative over the lower range of speeds that have previously been studied.

Where tyre and surface make direct contact with one another, adhesion is high, with frictional coefficients of the order 0·7 to 0·8 even at speeds of the order of 100 m.p.h. In wet conditions, however, direct contact between tyre and surface is impeded by the presence of the water film, and water is an effective lubricant for rubber. To obtain a high coefficient in wet conditions it is therefore necessary for the intervening water film to be displaced, or broken through, during the time each element of tyre and surface are in contact. As the speed rises, the time of contact is reduced, there is less time for the process to be completed, and it is essentially for this reason that coefficients on wet surfaces fall as speed is raised, reaching values of the order of 0·5 to 0·1 at 100 m.p.h.

Surface texture is the essential characteristic of a surfacing which determines how readily the lubricating action of the water film can be overcome. There are two main factors operative (*a*) " drainage," or the ease with which the bulk of the water film can escape from the zone of contact; and (*b*) the " shape " of the projections which constitute the surface. The second of these is the factor of primary importance.

As far as " drainage " is concerned the worst conditions arise with a smooth tyre on a perfectly smooth surface. The liquid film can only escape across the perimeter of the contact patch and under these conditions, the perimeter is a minimum. If the zone of contact is made more discontinuous by making a surface which only touches the tyre at isolated points, or by means of a tread pattern on the tyre, " drainage " is improved and it becomes easier for tyre and surface to come into contact in the time that is available. Thus, tyres with tread patterns have a beneficial effect in improving skidding resistance on those surfaces where there is insufficient " drainage " with a smooth tyre. As the results of the present tests show therefore, the effectiveness of a tyre tread pattern varies from surface to surface depending upon the surface texture.

It is the " shape " of the surface projections, however, which play the chief role in determining the skid-resisting properties of surfaces. Initially, the liquid film on a wet surface may have a thickness of the order of 0·020 in.; much of this film is displaced quickly, however, until the thickness diminishes to a value of the

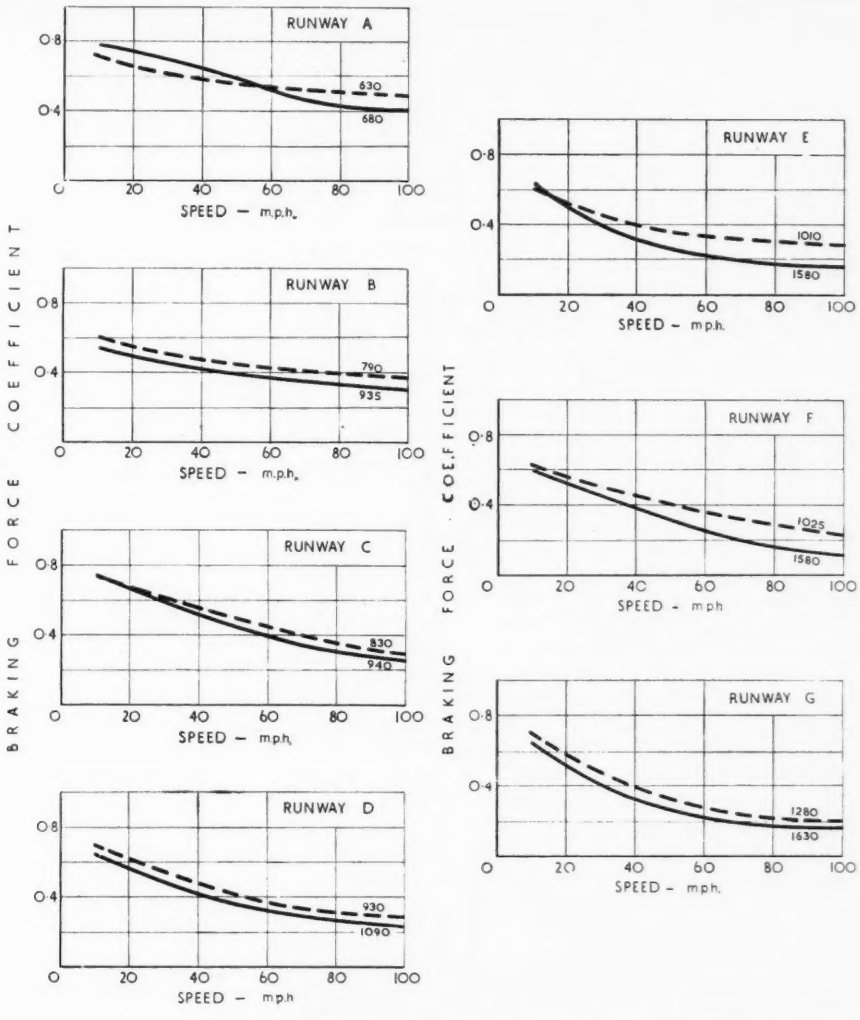


FIGURE 13. Curves showing results for wet runway surfaces.

——— Results with a smooth tyre.

— — — Results with a tyre with a simple tread pattern.

Figures on curves indicate skidding distance, in feet, from 100 m.p.h.

FIGURE 14 (*left*). Photograph of test tyre showing the damage caused when making braking tests on a dry runway at 100 m.p.h.

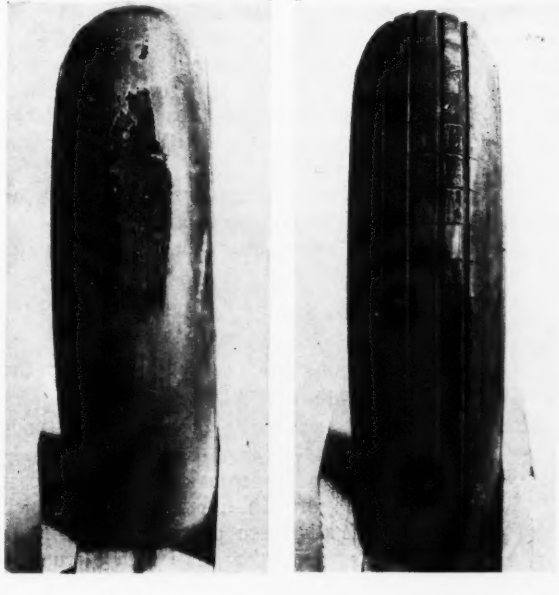


FIGURE 15 (*right*): Test tyres showing examples of wear caused by locking test wheel at speeds over 80 m.p.h. on wet surfaces.

order of 0·002 in. Films of this thickness are much more difficult to displace with a smooth tyre on a smooth surface. Where the surface projections make contact with a tyre, however, the shape of the projection determines the localised pressure. The sharper the projection the higher the pressure. If the edges are sharp and angular the localised pressures in small areas of the surface may be of the order of several thousands of pounds/sq. in. It is these intense pressures which ensure that the last traces of film are penetrated and that a high value of adhesion is obtained. Ultimately then the performance of a surface under wet conditions is determined by the " shape " of small portions of the surface with a scale of the order of a few thousandths of an inch. If these are sharp and harsh to the touch, a good skidding resistance will be obtained.

5.2. LOCKED WHEEL TESTING AND AUTOMATIC BRAKES

The results described in the tests were all obtained with a locked wheel and it is evident that, tested in this way, there are some important differences in the performance of different surfaces. Past test results have indicated, however, that in some circumstances, somewhat higher values of coefficient may be obtained if the wheel were arranged so that it was only just on the point of locking and skidding. It has been found, however, that even where this condition exists, it is a most difficult one to maintain in practice, since both the normal force and the frictional properties of the surface are subject to very marked variations as the wheel travels along. Unless, therefore, the wheel can be geared to run at some optimum rate of slip all the time, it will be virtually impossible to prevent it from locking at the first reduction of load or decrease of braking force. This condition of " impending skidding " where it exists, is therefore a highly unstable one under ordinary conditions. Automatic brakes which release the wheel, either as soon as it locks, or is decelerated violently, may be thought to have an advantage in enabling the impending skidding condition to be approached more closely. Tests with a car fitted with automatic brakes are showing, however, that while such devices have some very definite advantages, the resulting stopping distances on wet surfaces are invariably rather longer than distances obtained under identical conditions with locked wheels.

It appears, therefore, that distances assessed on the basis of locked wheel measurements can be taken as the optimum limit to which stops made with automatic brakes will tend.

6. Conclusions

The main conclusions which can be drawn from the results of the tests are as follows:—

(*a*) With the apparatus and test methods described in this paper it is possible to study the skid-resisting properties of surfaces at least up to speeds of 100 m.p.h. Factors which prevented the attainment of higher speeds in the present tests were either the length of runway available for tests or, as in the case of the longest runway, the uneven riding quality of the surface.

(*b*) On wet surfaces, skidding resistance diminishes with increase in speed, at least up to speeds of 100 m.p.h. At this speed the highest coefficient reached on a wet surface in the present tests was 0·5: generally on the different surfaces values were of the order of 0·2 to 0·3 and the lowest value was 0·1.

(*c*) Similar tests on a dry runway gave coefficients of 0·7 to 0·8 at speeds of the order of 100 m.p.h.

(*d*) Because of the lubricating effect of the liquid film the skidding resistance of all runways is likely to be lowered in wet conditions, particularly at the higher speeds.

(*e*) The relation between skidding resistance and speed in wet conditions varies from surface to surface, and only by direct measurement can the skidding resistance of a particular surface at a given speed be determined with any degree of certainty.

(*f*) A harsh surface texture is the essential requirement if a surface is to have a good skid resistance at high speeds in wet conditions. Thus films of tar or bitumen found on two of the concrete runways tested had an adverse effect on their skid-resisting properties.

(*g*) Even at high speeds tyre tread patterns can make a useful contribution to increased skid resistance and the simple tread pattern used in the present tests gave appreciably higher values of coefficient than a smooth tyre on some of the surfaces.

(*h*) In general the results of the tests show that at least up to speeds of 100 m.p.h. the skid-resisting properties of surfaces follow the same trends as shown by the results of previous tests at lower speeds. Essentially, it is the texture of the surface layer which is the important factor determining the skid-resisting properties of surfaces and so, as with road surfaces, it should be feasible to improve conditions, where slipperiness of runways in wet conditions is an important problem, by means of relatively inexpensive surface treatment.

Acknowledgments

In carrying out the tests described in this paper the Laboratory has received considerable assistance from a number of organisations and individuals. Especial thanks are due to Jaguar Cars Ltd., for their very ready co-operation in making available the car with which the tests were made, and to their test drivers whose skill contributed much to the successful completion of the programme of tests. Grateful acknowledgment is also due to the Firestone Tyre and Rubber Company who designed and made the special tyres with which the measurements were made. Thanks are also due to the

Air Ministry Works Directorate, the Ministry of Supply, and to the Ministry of Transport and Civil Aviation for co-operation in the preliminary examination of runways which might be suitable for test, and for help and assistance with the detailed arrangements for the runways that were tested. The authors acknowledge the co-operation and assistance received from the Air Traffic Control Staff and others at the various airfields at which the tests were made.

The work described in this paper was done as part of the programme of the Road Research Board of the Department of Scientific and Industrial Research and the authors acknowledge the permission of the Director of Road Research to publish this paper.

APPENDIX

DESCRIPTION OF THE APPARATUS USED IN THE HIGH SPEED TESTS ON RUNWAYS

THE BRAKING FORCE TRAILER

(*a*) *Constructional details*

A diagrammatic arrangement of the trailer is shown in Fig. 16. The test wheel is mounted in an aluminium plate to which are attached two light parallel link frames made from one inch diameter and $\frac{1}{8}$ in. thick steel tubes 36 in. long, cross-braced to increase their stiffness. This length ensures that inclinations of the links due to normal movements of the car on its springs, and so on, are sufficiently small to prevent towing or braking forces in the links seriously affecting the normal load on the test wheel. The parallel tubular frames terminate in bearings mounted in a steel towing bracket which turns about a long vertical bearing secured to the rear of the vehicle.

The sprung load of about 250 lb. is carried on a separate frame and is connected to the parallel tubular frames by rubber cord springs which have an effective rate of 80 lb./in. The suspension is damped by a hydraulic shock absorber adjusted to have a bump rate of the order of 4 lb./in. per second and a rebound rate of about 8 lb./in. per second.

Attached to the load frame and situated immediately behind the test wheel is a small castor wheel. When this is lowered, it raises the test wheel off the ground and the trailer and towing car can then be reversed without difficulty provided the trailer itself is locked in position about the towing bearing.

(*b*) *The braking system*

Details of the mechanism operating the trailer brake, which was arranged primarily to make use of existing available components, are shown diagrammatically in Fig. 17. The simple disc brake used to lock the test wheel was improvised for the purpose of the tests from the component parts of a standard Burman motor-cycle clutch. When the driver's switch is depressed a solenoid opens a valve allowing the reduced pressure in the engine induction manifold to operate a Dewandre type S11125 vacuum servo, which applies pressure through a lever to a hydraulic master cylinder. The pressure produced expands two rubber sacks, one operating the brake and the other locking a transverse clamp which prevents the trailer swinging from side to side while the test wheel is locked. The braking system is very rapid in its operation, taking only a short time to lock the test wheel.

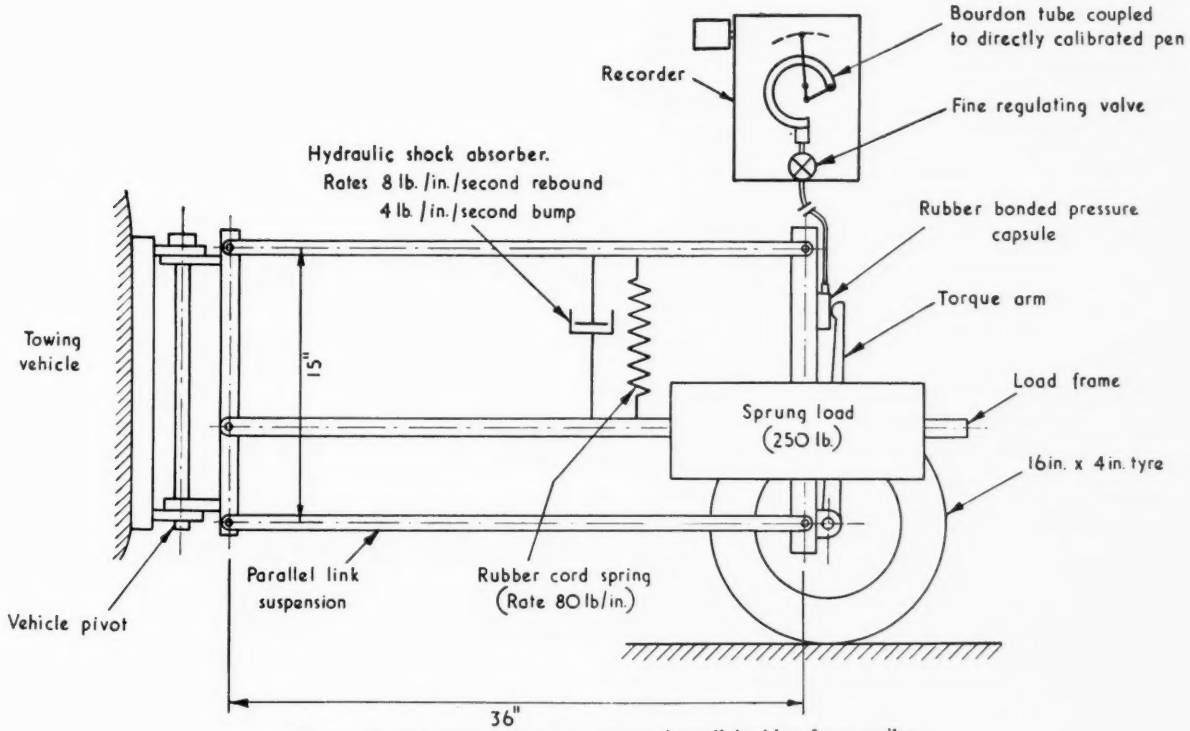


FIGURE 16. Diagrammatic arrangement of small braking force trailer.

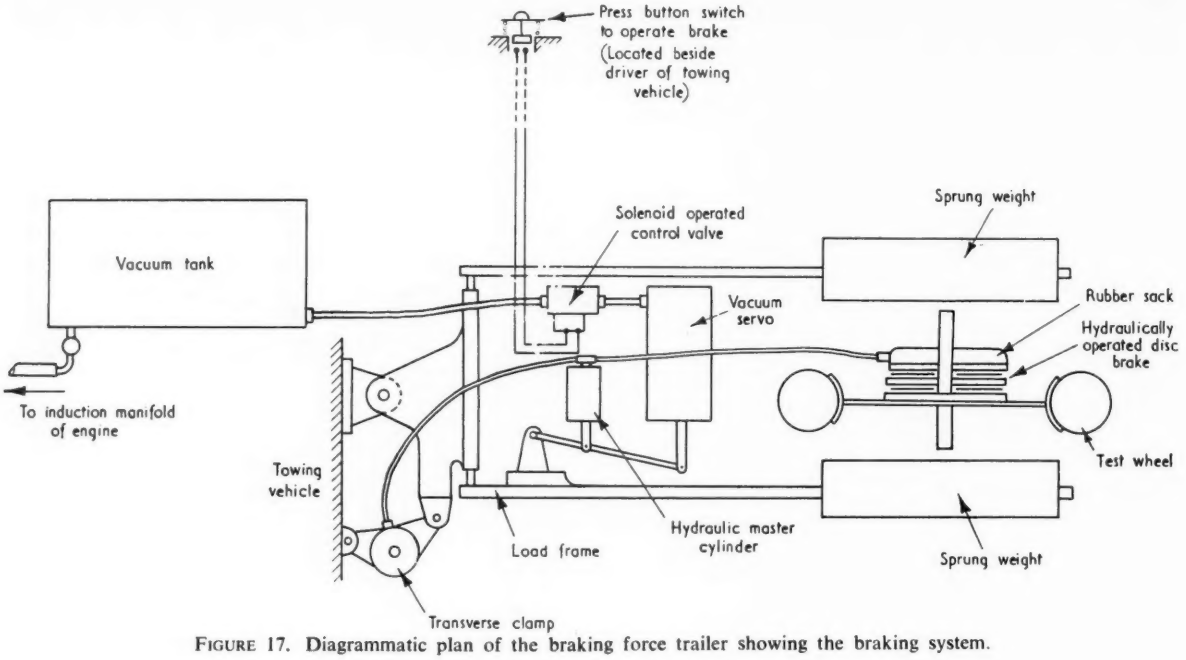


FIGURE 17. Diagrammatic plan of the braking force trailer showing the braking system.

Consequently, there is very little heating of the brake even in tests at high speeds and no difficulty was experienced with brake fade.

CALIBRATION OF THE RECORDING SYSTEM

The recording system is calibrated directly by placing the loaded test wheel on a steel plate, supported on hardened-steel balls running in guides so that it can move freely in a horizontal direction; known horizontal forces are applied to the plate, to represent the frictional forces existing between the sliding tyre and road surface. In this way a direct calibration of the braking force pen movement over the whole of its range is made.

LOAD VARIATIONS WHILE TESTING

To obtain the order of magnitude of the variations in load under test conditions at high speed, measurements were made of the actual displacement of the test wheel on its springs relative to the sprung weight while the braking tests were being made. A simple device operated by the brake servo system, which gave a record of the maximum vertical movement when the brake was applied, was fitted to the trailer.

It was found that even at 100 m.p.h. the maximum swing of the test wheel in relation to the load frame during the operation of the brake was of the order of only $\pm\frac{1}{4}$ in. This corresponds to a maximum variation in normal load of ± 20 lb.

TYRE GROWTH AND ITS EFFECT ON SPEED MEASUREMENT

At high rotational speeds, the test tyre "grows" and small errors in the calculation of speed from the test wheel revolutions can occur. To obtain a correction for this the speedometer of the towing car was first calibrated over timing strips and the indication of the test wheel contacts was calibrated by making records with the car driving at various constant speeds. As a further check, during tests on one of the runways runs were also made over timing tubes.

It was found that for speeds above 50 m.p.h. the actual test speed was slightly higher than the speed as calculated from a record of wheel revolutions and time. This error increased with speed and amounted to some 6 m.p.h. at 100 m.p.h. All the speeds quoted in the paper have been corrected for the effect of tyre "growth."

The Co-ordination of Aeronautical Research in The British Commonwealth*

by

L. P. COOMBES, D.F.C., B.Sc., F.I.A.S., F.R.Ae.S.

(Chief Superintendent, Aeronautical Research Laboratories, Commonwealth of Australia)

Introduction

I have chosen for my address the subject of Co-ordination of Aeronautical Research in the British Commonwealth, not only because this is a very important and vital matter, but because at this time there are being held in Melbourne meetings between aeronautical research workers from Australia, New Zealand, South Africa and the United Kingdom in certain fields of research. Simultaneously, in Canada similar meetings are being held between aeronautical research workers from Canada, United Kingdom and Australia.

Historical

Aeronautical research, like human flight, is of comparatively recent origin as far as serious work is concerned. In Australia we can be proud to have had one of the pioneers—Lawrence Hargreaves—while the Wright Brothers based the design of their aircraft on experiments with aerofoils carried out in a wind tunnel of their own design. In the United Kingdom the Aeronautical Research Committee, now elevated to the dignity of "Council" began its work in 1909 and ante-dated by several years the American N.A.C.A., which was created in 1915. Aeronautical research in other British Commonwealth countries was not carried out until between the First World War and the Second and even now the only countries of the British Commonwealth doing such research on any extensive scale are the United Kingdom, Canada and Australia; New Zealand, South Africa and India do only a small amount of work, principally in universities.

The work in Australia assumed sizeable proportions in 1938 when the Aeronautical Research Laboratory was founded by the Commonwealth Government. During the 1939-45 War, the major portion of the work was devoted to *ad hoc* problems, but a certain amount of basic research was done and there were clear indications of useful avenues of research which might be carried out when the pressure of events diminished. However, the Aeronautical Research Laboratories' staff were concerned as to whether they might, in fact, be duplicating research work already being done in the United Kingdom or elsewhere in the British Commonwealth, so that some form of co-ordination seemed essential.

In 1944, Dr. M. W. Woods of A.R.L. and I, while overseas, took the opportunity to raise the matter with the Aeronautical Research Council. Since the war was far from over, the approach was somewhat premature, and the interest aroused was consequently perfunctory. Later, however, the United Kingdom approached this question of co-ordination from a different angle. The research effort needed to keep in the van of progress in the rapidly advancing science of aeronautics was so great that co-ordination of the effort of all the British Commonwealth countries would be a substantial advantage both to the United Kingdom and the British Commonwealth as a whole. Not only would there be increased research resources, but there were geographical areas in other countries where flight research and special tests could be carried out more advantageously than in the confined spaces and mediocre climatic conditions of the United Kingdom. Accordingly, the British Government took the initiative of calling a Commonwealth Conference on Aeronautical Research in London, in June, 1946. This was attended by delegates from Australia, Canada, New Zealand and South Africa, with observers from the U.S.A.

The 1946 Meeting in London

It is of interest to recall some of the statements made at this meeting. Professor Goldstein, Chairman of the Aeronautical Research Council, spoke on the urgent need for research with very high priority on certain items. He instanced new types of laboratory and flight testing equipment; research on high speed flight directed to high speed subsonic civil aircraft and the penetration of the sound barrier for military aircraft; the reduction of drag by inducing laminar flow over wings by suction so as to reduce the cost of operating civil aircraft, and many other less important items.

In relation to the sound barrier the use of pilotless models in a large uninhabited area was mentioned. The Canadian delegate said that Canada had great uninhabited spaces but these usually consisted of forests and lakes where recovery of models would be difficult (Fig. 1). Air Commodore Wackett, one of the Australian delegates, spoke of a preliminary investigation which had been made to use the Central Desert for an Aeronautical research range, and mentioned the role that transport aeroplanes would have to play in such a development. Professor Goldstein forecast that air transport facilities would have to be provided for effective co-ordination between research establishments in the Dominions and in Great Britain. In the light of subsequent history, these observations were almost prophetic. High subsonic speed civil aircraft are an accomplished fact; military aircraft have not only penetrated the sound barrier, but speeds of two and even

*An address given to the Melbourne Branch of the Australian Division of the Royal Aeronautical Society on 17th March 1955, by Mr. Coombes as the retiring Chairman of the Branch.

FIGURE 1. A great uninhabited space in Canada.

more times the velocity of sound are being considered for new fighter types.

The "large open space" has been furnished by Australia and is now the Woomera Rocket Range. Air transport facilities for aeronautical research workers and equipment have been provided between the United Kingdom, Canada and Australia; in our case a regular courier service of Hastings aircraft flies between England and Australia. Only the maintenance of large areas of laminar flow on the wings of aircraft has not progressed beyond the research stage.

Sir Ben Lockspeiser, then Chief Scientist of the Ministry of Supply, mentioned that suitable suction aerofoils had been tested in wind tunnels in the United Kingdom, but their application to actual aircraft remained to be done. He suggested that Australia might accept this item. As a consequence, and after considerable wind tunnel work in the Aeronautical Research Laboratories, a glider with a 30 per cent. thick suction wing was built by the Government Aircraft Factories and flown successfully by the Aircraft Research and Development Unit of the R.A.A.F. (Figs. 2, 3). This work, as might be expected, took some years to complete, but as a practical example of co-ordination in aeronautical research, not only between countries, but between establishments within Australia, the flight development of the suction wing would be hard to better.

The outcome of the Meeting was a recommendation to the various Governments concerned that a Commonwealth Advisory Research Council be set up with the following terms of reference:—

(*i*) To promote the progress, and to encourage the widest practical extension, of aeronautical research throughout the Commonwealth.

(*ii*) To review the progress of aeronautical research within the Commonwealth in order to advise on the broad planning of programmes and on the facilities required.

(*iii*) To advise on means for disseminating scientific information on aeronautics within the Commonwealth.

(*iv*) To promote the interchange, secondment and visits of scientific personnel within the Commonwealth.

(*v*) To consider broad problems of aeronautical interest concerning the Commonwealth as a whole submitted to it by Commonwealth bodies concerned with aviation and to make recommendations for their solution.

(*vi*) To report after each Conference to the appropriate research authorities.

By agreement of the participating countries this body was set up with permanent headquarters in London.

Meetings of C.A.A.R.C.

AUSTRALIAN MEETING 1948

The first meeting of this Council was held in Australia in 1948, and was attended by strong delegations from the United Kingdom, Canada, South Africa, New Zealand, and of course, Australia.

An item of great interest to the Council was the partly completed suction wing glider which was being built at the Government Aircraft Factories. It was most gratifying to the Council that the suggestion made in 1946 was being carried into effect, since it involved a great deal of effort in terms of scientific, industrial and Service manpower and money.

The meeting was a great success and it set the pattern for all subsequent meetings of the Council. The presence of eminent aeronautical research workers from overseas was a great stimulus to the local scientists. The technical discussions held as part of Council business engendered a great deal of enthusiasm among the Australian workers, some of whom saw for the first time in the flesh people whose names were almost legendary. Apart from fulfilling its terms of reference generally, a major advance was made in relation to Item 3, the dissemination of scientific information on aeronautics within the Commonwealth.

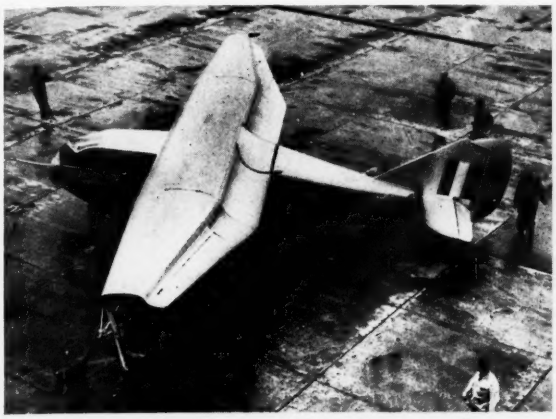


FIGURE 2. Suction wing glider built in Australia.

FIGURE 3. Suction wing glider in flight.

This was suggested by the Canadian delegates, and has come to be known as the Co-ordination Scheme. It consisted in delineating the most important fields of aeronautical research and appointing in each field a co-ordinator from each interested Commonwealth country. The Chief Co-ordinator would be responsible for making a report on the activities in his field to the next Council meeting, the information being supplied by all co-ordinators on behalf of their own countries. Apart from this review of activity, a major advantage of the scheme was that the co-ordinators were empowered to correspond directly with one another and to exchange information. Thus, formal and cumbrous official channels of communication were unnecessary and the direct flow of information between research workers, previously regarded as an Utopian dream, became a reality when the Council's report was finally approved by the participating countries.

It will be realised how far the Scheme had progressed when we recall that Co-ordinators' Meetings have been regularly held in various countries and that co-ordinators from the United Kingdom, South Africa and New Zealand are now meeting in Australia to discuss Structures, Special Instrumentation and Meteorological Effects, while other groups of co-ordinators from the United Kingdom and Australia are meeting simultaneously in Canada to discuss Low Speed Aerodynamics, Supersonics and Extreme Climatic Conditions of Operation. Most of the delegates travelled by official R.A.F. and R.C.A.F. transport.

CANADIAN MEETING 1950

The second meeting was held in Canada in September 1950, and delegations from the United Kingdom, Australia, New Zealand, and South Africa met with members from the host country (Fig. 4). The Canadian Meeting followed the pattern which had been established in Australia, business meetings of the Council being interspersed with technical discussions and visits of aeronautical research interest.

At the Australian Meeting Mr. W. G. A. Perring, then Director of the R.A.E., had proposed on behalf of the United Kingdom Government that a Commonwealth supersonic tunnel of large size and needing at least 250,000 h.p. should be built at some suitable place in the Commonwealth for the benefit of all. He asked that enquiries be made as to whether there were any suitable locations with adequate water power within the Commonwealth. Before going to Canada, I had examined this possibility in Australia and found that a proposed new power system for the Great Lake in Tasmania would fit into such a scheme. A head of about 2,500 feet would be directly available and the proposed pipeline was to emerge at a place quite suitable for a research establishment.

The Commonwealth supersonic tunnel proposal was discussed by the 1950 meeting and to give perspective to the proposal, the Canadians drove the delegates to a new hydraulic power station of 250,000 h.p. which was being constructed about 150 miles from Ottawa (Fig. 5). The magnitude of a water power station of this size and the difficulties associated with its construction were brought home to the members of the Council. Nevertheless, Mr. Perring made such a strong case for the need for such a facility in the Commonwealth, especially in relation to guided missiles, that Council endorsed the proposal in principle without deciding on the precise location. It is not altogether surprising that the implementation of this proposal did not commend itself to the various Governments concerned since, clearly, the country in which the tunnel was located would have had to bear a considerable burden in constructing, staffing and running the Establishment, even though in theory it was a co-operative effort. Nevertheless, the technical value of such a facility would have been very great to the British Commonwealth.

UNITED KINGDOM MEETING 1953

The Third Meeting of the Council was held in September 1953, in the United Kingdom. The date had been chosen so that delegates from other countries could attend the annual S.B.A.C. Show at Farnborough and the Fourth Anglo-American Conference in London. There was a good attendance; delegates came from Australia, Canada, New Zealand and South Africa and for the first time India joined the Conference (Fig. 6).

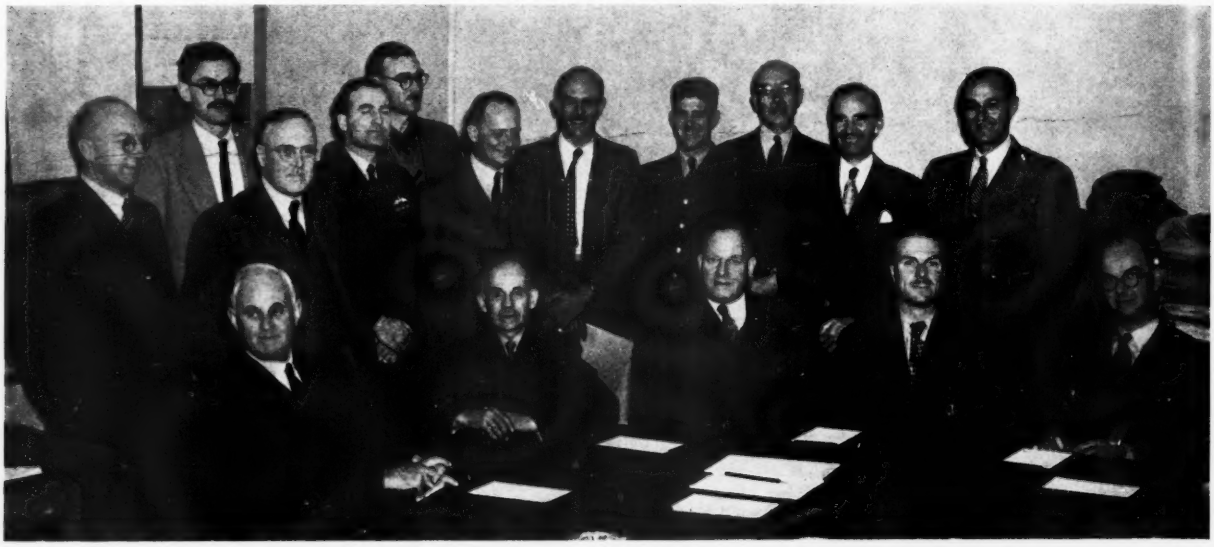


FIGURE 4. C.A.A.R.C. Delegates at the Arnprior Flight Research Unit of the National Research Council, Canada. (*Seated L. to R.*): Sir Leonard Bairstow (U.K.); Sir Harry Garner (U.K.); The late Mr. W. G. A. Perring (U.K.); Dr. J. J. Green (Canada); Professor A. R. Collar (U.K.). (*Standing L. to R.*): Dr. E. R. Cooper (N.Z.); Professor D. A. Mordell (Canada); Dr. E. Marsden (N.Z.); Gp. Capt. E. Hey (Aust.); Professor A. V. Stephens (Aust.); Mr. L. P. Coombes (Aust.), Head of N.R.C. Flight Research Group; Gp. Capt. G. G. Truscott (Canada); Mr. J. H. Parkin (Canada); Mr. E. T. Jones (U.K.); Colonel C. S. Kotze (Canada).

The pattern of the United Kingdom Meeting differed in one respect from that followed by Australia and Canada. The aeronautical research activity in the United Kingdom is spread over several different Establishments and it was therefore left to the delegates to make their own private arrangements for visits. The normal pattern of a combination of Council and Technical Panel Meetings was followed. In these Technical Panels the experts in each field were gathered from various Establishments to sit with Council delegates. By bringing together such a powerful collection of research talent, it was possible within the space of half a day or so devoted to each field, to crystallise opinion on the research work in progress in various countries and to formulate concrete suggestions for the most profitable and important lines of research for the immediate future.

One useful product of the C.A.A.R.C. Meetings which has not yet been mentioned is the special papers written for them. Over 100 were submitted to the United Kingdom Meeting, including the Chief Co-ordinators' Reports from the various fields of research activity. Some of these papers were quite outstanding in their degree of originality and stimulus to thought. In this, Australia did its part. The Australian Aeronautical Research Committee had, nearly a year ahead, decided what activities would be covered in these special reports and arranged for them to be written.

Review of the Work of C.A.A.R.C.

The Commonwealth Aeronautical Research Council has now been in existence for nearly ten years, and we can take stock of its achievements and shortcomings, and also consider what should happen in the future. Let us first consider whether it has achieved its broad aims. These are taken slightly out of order.

2. *To review progress of Aeronautical Research within the Commonwealth in order to advise on the broad planning of programmes and on the facilities required.*

C.A.A.R.C. has certainly carried out this function at all its meetings. It has conducted technical discussions with aeronautical research workers and has had the co-ordinators' reports, which help considerably. For those who wish to profit by advice, the Council's reports have indicated clearly the most important fields of research at the time, and have on occasion suggested particular countries where the research might be done and the facilities or equipment required. There can be little doubt that this particular aim has been achieved. Thus, looking back to the 1953 Council report, one finds that seven out of the eight main recommendations have received active attention in Australia.

3. *To advise on means for disseminating scientific information on aeronautics within the Commonwealth.*

4. *To promote the interchange, secondment and visits of scientific personnel within the Commonwealth.*

The two aims can be taken together as the co-ordination scheme has also helped to promote the visits of scientists. The situation is very satisfactory. The co-ordination scheme whereby persons are selected in each country in the main fields of endeavour, is working well. There is no reason why any research worker should lack knowledge of what is going on elsewhere, as he can transmit a query through his local co-ordinator.

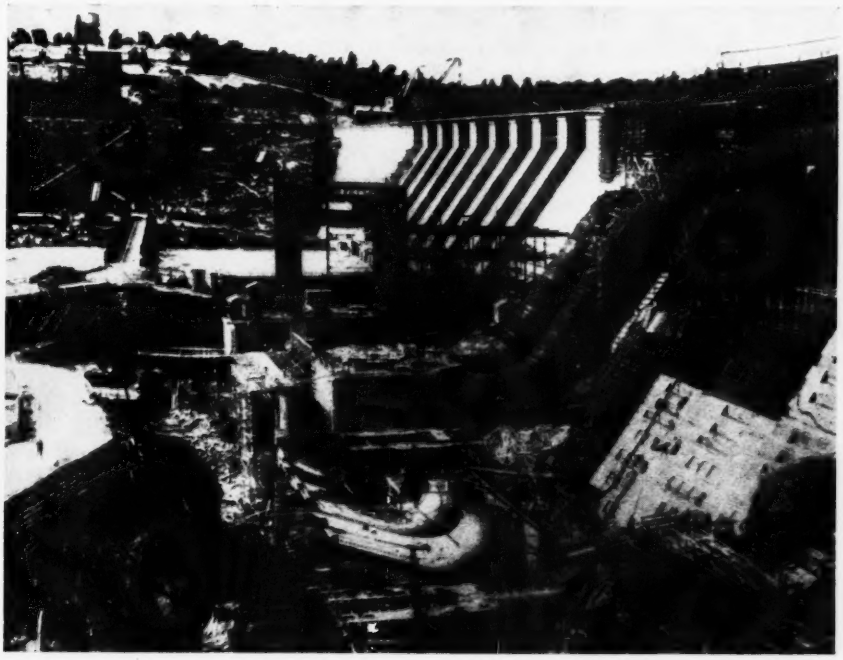


FIGURE 5. 250,000 h.p. water power station at Des Joachims, Ottawa, Canada, visited by 1950 meeting of C.A.A.R.C.

In addition, within the limits of time and effort which these busy people can devote, news letters are exchanged and the periodical co-ordinators' reports survey the fields generally; a large number of special reports and reviews are also written for the Council Meetings every two or three years. One can fairly claim that the co-ordination of information has been attained.

The visits and interchange of scientists at all levels has made an auspicious beginning and is gathering momentum. The biggest factor in this is the Hastings service which makes travel between England and Australia very much easier than if the people concerned were sent by commercial transport and the costs inevitably appeared against the finances of the Establishments. For example, transport for the people from Australia to Canada was arranged by Hastings to the United Kingdom and by the R.C.A.F. Transport Command across the Atlantic; the same sort of thing was also arranged for people in other countries. A number of Co-ordinators' Meetings have been staged at various times. As mentioned earlier, one is in progress in Melbourne at this time, and simultaneously in three other fields meetings are being held in Canada.

FIGURE 6.
COMMONWEALTH ADVISORY AERONAUTICAL RESEARCH COUNCIL

Third Meeting, London, 1953

(*Front Row*) Mr. S. Ramamritham, Dr. O. H. Wansbrough-Jones (now Sir Owen), Mr. J. H. Parkin, Professor A. G. Pugsley (Chairman), Professor A. V. Stephens, Dr. E. Marsden, Mr. J. P. de Wit.

(*Second Row*) Mr. L. P. Coombes, Dr. V. Armstrong, Sqdn. Ldr. L. C. Woods, Air Vice-Marshal E. C. Wackett, Commandant A. J. Mossop, Professor E. J. Richards.

(*Back Row*) Mr. A. A. Hall (now Sir Arnold), Mr. E. T. Jones, Dr. J. J. Green, Dr. A. A. Griffith, Mr. R. W. G. Gandy.

(*Absent*) Sir Harry Garner, Mr. J. L. Orr, Mr. A. D. Wood, Dr. D. C. MacPhail, Mr. A. M. Schady, Mr. J. L. Nayler.

Apart from this, visits of individual scientists in both directions have occurred very frequently and Australia, in particular, has sent a number of junior and senior research workers to the United Kingdom for periods of one to two years. In this scheme there are advantages on both sides. The Australians receive the best possible training in their particular fields at the United Kingdom Establishments and the experience is of immense value when they return to Australia. Since they are all selected men with excellent qualifications and backgrounds, these Australian scientists are extremely useful temporary members of the United Kingdom staffs and are warmly welcomed for this reason. We can therefore say that this objective of C.A.A.R.C. is being satisfactorily fulfilled.

5. *To promote progress and to encourage the widest possible extension of aeronautical research in the Commonwealth.*

This is the first of the main aims of C.A.A.R.C. and here one must conclude that the achievements fall short of what one might reasonably hope for. Without doubt, meetings of the Council and of co-ordinators stimulate very strongly the local research workers. Moreover, these visitors speak with authority and their influence on the people who hold the purse strings or otherwise govern the research operations of the laboratories is considerable, and helps to get approval for research projects which otherwise might have a stormy passage through the governing committees.

One must record, however, that there are no very clear instances of initiating or increasing in large measure aeronautical research activity. One would imagine that the workers in South Africa and New Zealand would very much appreciate some more positive action to provide them with wind tunnels or other facilities, just as we would appreciate effective support for many of the research projects which we would like to undertake. Here one recalls the large co-operative tunnel proposed by Perring.

The 1948 Meeting set up a Power Panel to review the engineering, strategic and economic aspects of setting up an establishment within the Commonwealth with power resources capable of development to 500,000 h.p. within 25 years. By the 1950 Meeting in Canada this objective had become more specific and sites within the Commonwealth were mooted. Nevertheless, although the Council recommended the scheme, its magnitude frightened the Governments concerned and the scheme died with its protagonist.

How much further ahead the United Kingdom would have been in its development of guided weapons and supersonic aircraft if this large supersonic tunnel facility had been built, is hard to say, but it must be recorded as a failure of C.A.A.R.C.

6. *To consider broad problems of aeronautical interest concerning the Commonwealth as a whole submitted to it by Commonwealth bodies concerned with aviation and to make recommendations for their solution.*

An important aspect of promoting aeronautical research is the initiation of actual research projects which are of importance and benefit to the whole Commonwealth and which are carried out by one or more of the countries in collaboration. Such projects fall into two classes; fundamental investigations which can be made by research establishments themselves, and projects involving expensive construction by industry and operation by Service Departments.

In the first category there are now in progress in Australia two co-operative projects, which are joint efforts between the United Kingdom and Australia and which are co-ordinated under the scheme. These happen to be classified projects and they can only be referred to as examples and not in detail. In other cases the joint effort is more loosely controlled, such as fatigue of aircraft structures in the United Kingdom and Australia, and icing and low temperature operation between the United Kingdom and Canada.

The second class of project is almost unknown, the classic exception being the flight development of the suction wing, which I have already instanced. We want more of these projects where something tangible results and which capture the interest of a wide circle of people both in and outside the aeronautical community. One feels that there is a great potential in the Dominions waiting to be tapped. In Australia and Canada there are substantial research Establishments with good equipment and well-trained, highly qualified and enthusiastic staffs.

One would like to hear more suggestions by the senior partner in this Commonwealth group—the United Kingdom—as to worthwhile research projects which cannot be undertaken in the Mother country because of more urgent commitments, but which are important and will have a significant effect upon the future breed of aircraft. Such projects must be carefully chosen to suit the staff and equipment in regard to magnitude of effort, so that they will be completed in a reasonable time; equally important, the group chosen to undertake the work must have a considerable natural interest in it if really good original work is to be forthcoming.

If these conditions are fulfilled, it should be possible to avoid duplicating the effort, and certainly this is most desirable because there is nothing so disheartening and frustrating as to find that a project in which one has been putting one's best efforts for a considerable time has been duplicated and completed in some other country ahead of one's own.

In conclusion, I believe that Commonwealth co-operation in aeronautical research has achieved a significant part of its objectives, but the really worthwhile dividends have been exploited in only a small measure. I feel that this matter is so important to Australia in particular that it is worthy of the greatest consideration from all concerned.

Aerial Systems For Aircraft

by

R. A. BURBERRY

(*Standard Telephones and Cables Ltd.*)

1. Classification

The range of frequency for which aerial systems for aircraft are required is immense: the highest used frequency is over one hundred thousand times the lowest. Very differing techniques are required throughout this range and this lecture will be chiefly concerned with the principles on which these techniques are based, rather than on individual aerial systems.

One method of classification of aerials is by their operating frequency or wavelength range. The following division has been chosen to avoid overlapping by various equipments:

Low Frequency (L.F.)	Below 2 Mc/s.
High Frequency (H.F.)	2 – 20 Mc/s.
Very High Frequency (V.H.F.)	20 – 250 Mc/s.
Ultra High Frequency (U.H.F.)	250 Mc/s. – 1,250 Mc/s.
Super High Frequency (S.H.F.)	Above 1,250 Mc/s.

Within these ranges there are a number of aircraft radio equipments, some of which are listed in Table I.

Apart from this method of classification the operating wavelength can be related to the major dimensions of any aircraft. This system is very valuable in assessing the performance of aerials on a particular aircraft and all the aerials fall into four classes. Taking the aircraft span S as the parameter, these classes are:—

1. Wavelength greater than S (say $\lambda > 6S$)
2. Wavelength of the order of S ($\lambda/6 < S < 3\lambda$)
3. Wavelength less than S ($S > 3\lambda$)
4. Wavelength much less than S ($S > 20\lambda$)

These are, admittedly, very loose divisions and the range of aircraft equipment in each class will vary from one aircraft to another. Roughly the first three classes correspond to L.F., H.F. and V.H.F. respectively.

2. Electrical Criteria

In developing an aircraft aerial three electrical criteria have to be satisfied. These are:

(*a*) Radiation pattern.
(*b*) Impedance.
(*c*) Gain.

The relative importance of these factors depends on the function of the aerial and the frequency at which it operates.

A Section Lecture given before the Society on 26th April 1955.

2.1. RADIATION PATTERN

The intensity of radiation on the surface of a sphere whose centre is a transmitting aerial constitutes its solid radiation pattern. While this three-dimensional figure is of considerable value in research into aerials, all the information it provides is not always necessary. Much can be gained from the radiation pattern in three mutually perpendicular planes; these are known as the principal radiation planes. Most important of these is the azimuth plane; the others are the fore-and-aft elevation and transverse elevation planes, and Fig. 1 shows their disposition with respect to the aircraft. Further information can be obtained from radiation planes parallel to the principal azimuth plane.

The pattern is known as the absolute radiation pattern when its values are expressed in absolute field strength. It is more usual to use relative patterns as these are comparatively simple to measure. The reference level is often that of the aircraft line of flight, *i.e.* 0° azimuth and elevation, as this is most useful for assessing flight performance.

2.2. GAIN

Relative field strengths can be converted to absolute values when the aerial gain is known. The power gain of an aerial may be defined as the ratio of powers which have to be supplied to it and to a reference aerial to give the same field strength at a constant distance. The absolute field strengths for the reference aerial can be calculated and so those for the aerial in question may be found.

The absolute standard of reference is an isotropic radiator having equal field strength in every direction. Such an aerial cannot be realised practically and the practical reference is the half wave dipole, which will be discussed in detail later.

2.3. IMPEDANCE

The radiation pattern of an aerial is determined by the distribution of current and voltage along its elements. The ratio Voltage/Current is a complex quantity known as impedance and consists of resistive and reactance components. The power transmitted to an aerial is partly dissipated as heat in the loss resistance and, partly radiated. For aerials which are not appreciably less than a quarter wavelength long the loss resistance is usually negligible.

The term aerial impedance will be taken to mean the impedance at the junction of the aerial to its transmission line, otherwise known as the feed point

impedance. It is a function of the dimensions of an aerial expressed in wavelengths and therefore varies with frequency for any aerial of fixed size.

A transmitter can deliver the most power to any aerial when the impedances of the two are the same, when they are said to be matched. In practice these two units may be physically separated and connected by a transmission line which is itself matched to the transmitter. When the aerial is not matched periodic voltage variations occur along the line and form a standing wave pattern. The ratio of maximum to minimum voltage on the cable is known as the voltage standing wave ratio (V.S.W.R.) of the aerial to a cable of that impedance. The presence of a standing wave implies reflection of some of the transmitted power and the V.S.W.R. is therefore a measure of the efficiency of the aerial to radiate that power. In general a larger standing wave ratio can be tolerated when the aerial is connected to a receiver than when it is transmitting. In the latter state the allowable V.S.W.R. is determined by the power loss or change in frequency it causes at the transmitter.

3. Basic Aerial Forms

3.1. THE DIPOLE

The simplest electrical form of aerial is the dipole, a clear appreciation of whose characteristics is essential to a better understanding of so many aircraft aerial systems derived from it. The centre fed dipole consists of two thin conducting cylinders, collinear, and joined to a two wire transmission line at their adjacent ends. The arms are equal in length and of a diameter negligible compared with their length.

3.1.1. *Impedance*

The current and voltage vary periodically along the arms, repeating every half wavelength but decreasing in amplitude with distance from the centre of the aerial because of radiation from each portion of it. The current will always have a minimum at the distant ends and the voltage a maximum. In consequence the impedance at the feed point varies with length in the manner shown in Fig. 2. The first purely resistive value occurs when the total length of the dipole is in the neighbourhood of a half wavelength and the phrase " half wave dipole " will therefore be taken to mean an

TABLE I

AIRBORNE RADIO EQUIPMENTS

Equipment	*Frequency*	*Function*	*Aerials*	*Polarisation*
L.F.				
Decca	70-120 kc/s	Position fixing	Omni-directional reception	—
Communication	150-500 kc/s	Long range reception	Omni-directional reception	—
A.D.F.	150-1500 kc/s	Bearing indication	Directional reception	—
Loran	1750-2000 kc/s	Position fixing	Omni-directional reception	—
H.F.				
Communications	2-20 Mc/s	Two-way communication	Omni-directional transmission and reception	Primarily vertical
V.H.F.				
Gee	20-85 Mc/s	Position fixing	Omni-directional reception	Vertical
Communications	100-156 Mc/s	Two-way short range communication	Omni-directional transmission and reception	Vertical
I.L.S. (Instrument Landing System)				
(*a*) Localiser	108-112 Mc/s	Azimuth approach aid	Primarily forward and rearward reception	Horizontal
(*b*) Marker	75 Mc/s	Position marking on approach and *en route*	Downward reception	Horizontal
(*c*) Glidepath	328-336 Mc/s	Elevation approach aid	Forward reception	Horizontal
V.O.R. (V.H.F. omni-range)	112-118 Mc/s	Bearing indication	Omni-azimuth reception	Horizontal
I.F.F. III (Identification Friend or Foe)	157-197 Mc/s	Military ground-to-air or air-to-air identification	Spherical coverage reception and transmission	Vertical
Rebecca } 200 Mc/s D.M.E. }	200-240 Mc/s	Distance measurement and homing indication	Omni-azimuth transmission and reception Forward directional reception	Vertical
U.H.F.				
Communication	225-400 Mc/s	Two-way communication	Omni-direction transmission and reception	Vertical
1000 Mc/s D.M.E.	960-1215 Mc/s	Distance measurement	Omni-azimuth transmission and reception	Vertical
S.H.F.				
Altimeters	4200 Mc/s 1600 Mc/s band	Height above terrain	Downward directional transmission and reception	Not applicable
Search Radar (Cloud and Collision warning)	Variously 3000 Mc/s 6000 Mc/s 9000 Mc/s	Radar delineation of high ground, aircraft, cu-nim cloud giving bearing and range	Forward azimuth out to 90° from line of flight within limited degree of elevation. Highly directional transmission and reception scanning	—
H2S	9000	Map painting	Forward and downward directional transmission and reception. Scanning	—

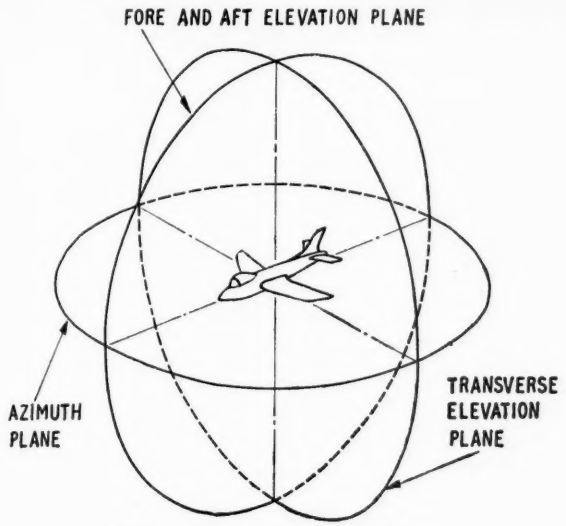


FIGURE 1. Principal radiation planes.

aerial of approximately this dimension. It will be seen that further resistance points or resonances occur at multiples of half wavelengths, the resistive values being alternately high and low.

If the arms of the dipole are equal the aerial is symmetrical about a plane perpendicular to the axis. A metallic sheet of infinite extent can be put in this neutral plane without affecting the characteristics of the aerial. One arm then appears as the image of the other in this plane and one element may be removed without affecting the radiation of the other. The impedance of the unipole thus formed is half that of the equivalent dipole. At the half wave length resonance the dipole has a radiation resonance of approximately 73 ohms, the unipole being $36\frac{1}{2}$ ohms. These are convenient values for connecting to coaxial transmission lines whose characteristic impedance lie between 50 and 80 ohms, so many aerials are of this dimension.

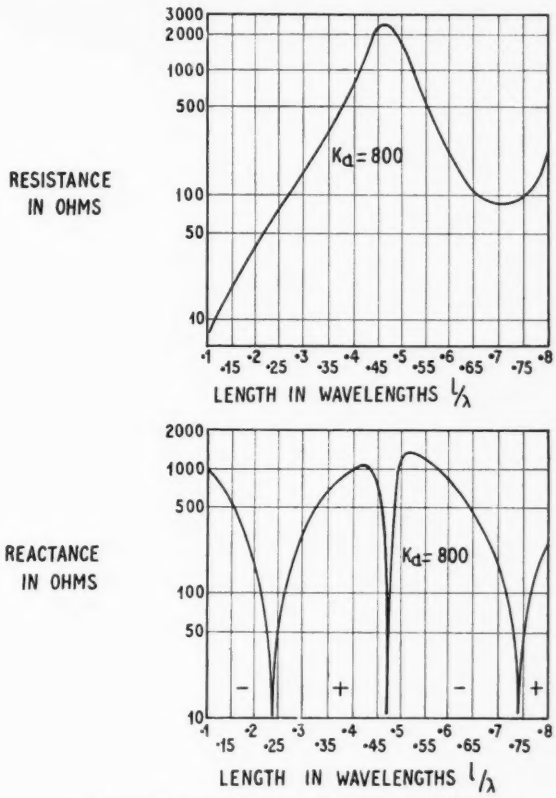


FIGURE 2. Impedance of thin centre-fed dipole.

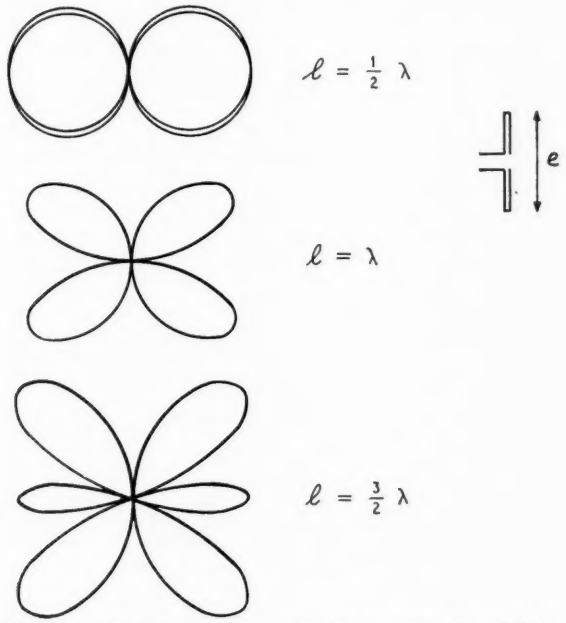


FIGURE 3. Radiation pattern of dipoles as a function of their length.

3.1.2. *Radiation Pattern*

The electric radiation vector of a dipole is parallel to its axis and has a maximum in the equatorial plane. For an aerial whose cross-sectional dimensions are small, compared with the wavelength, the radiation pattern is a circle in this plane and planes parallel to it. The radiation along the axis of the dipole is zero whatever the length of the elements. The pattern in a plane containing the dipole depends on the aerial length: some representative patterns are shown in Fig. 3 where it will be seen that for aerials greater than one wavelength additional zeros will occur. These radiation diagrams are of little practical use in aircraft radio so further discussion of dipoles will be confined to the near half-wave type.

3.1.3. *Gain*

Since the dipole has no axial radiation its field strength in the equatorial plane is greater than that of an isotropic radiator. Its power gain is 1·64 in that direction while the quarter wave unipole on an infinite

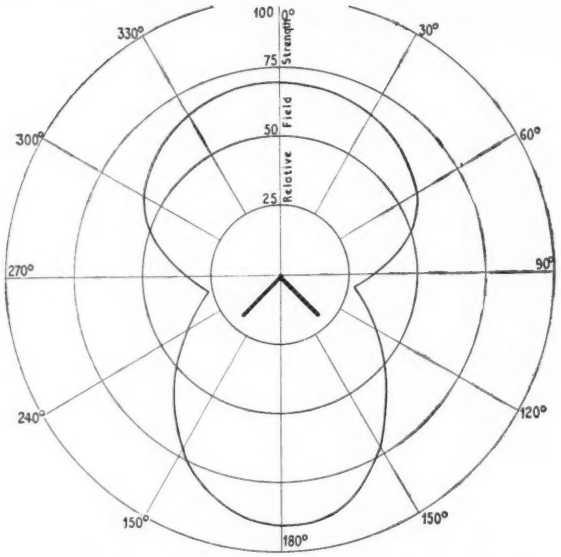


FIGURE 4. Radiation pattern of a Vee aerial.

sheet has a gain of 0·82, both compared with the absolute standard.

3.1.4. *Modified radiation patterns*

A straight horizontal dipole will give a figure-of-eight radiation pattern in the azimuth plane. It is impossible to obtain a circular pattern from a single dipole but a sufficiently good approximation is made by bending the elements to form a U or V shape. I.L.S. localiser aerials are commonly of this form and may be either mounted above the aircraft fuselage on a pedestal, or on either side of the tail fin. A typical pattern is shown on Fig. 4. The fin mounted system is generally more efficient as its signal level is higher in the azimuth plane.

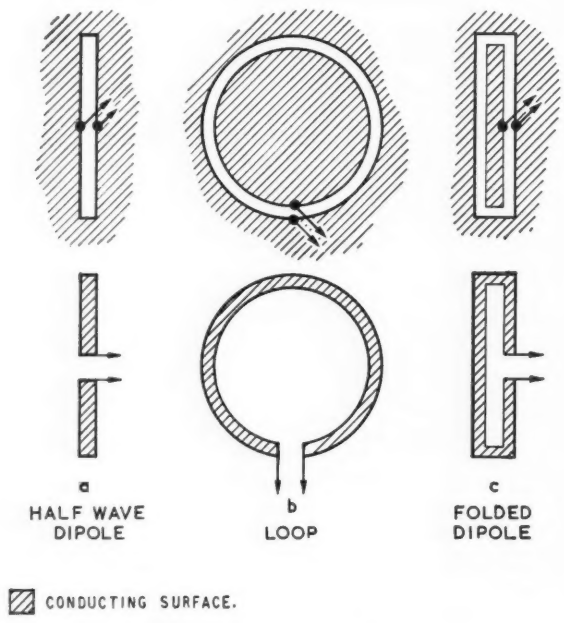


FIGURE 5. Slot analogues.

3.2. THE LOOP AERIAL

In its simplest form this comprises a single turn loop of wire having a small gap in it across which is connected a transmission line. When its diameter is small compared with the wavelength, the radiation pattern in the plane of the loop is a circle, while axially it is a figure-of-eight with zero radiation along the axis. When the dipole and loop both have vertical axes their radiation patterns are the same, but the loop has a horizontal electric vector while the dipole's is vertical. They are thus complementary devices.

When the loop diameter is increased the maximum radiation ceases to be in the plane of the loop and for certain diameters the signal may actually be zero. Such systems do not have many applications in the aircraft radio field.

The radiation resistance of a loop is proportional to the square of its area in wavelengths (for small diameters). Thus a loop of a quarter wavelength will have a resistance of about 8 ohms, while that of a loop of twice this diameter is about 120 ohms.

3.3. THE SLOT AERIAL

A hole cut in a large metallic sheet and suitably energised can act as a radiating system analogous to the aerial of the same shape. Thus the counterpart of the half wave dipole is a rectangular slot whose major axis is a half wavelength and whose width is simply related to the dipole cross section. The slot fed at the centre of its two long edges corresponds to the centre fed dipole. Similarly the slot form of the loop aerial is an annulus with transmission line connected to the inner and outer edges. Some aerials and their slot analogues are shown in Fig. 5. Not all aerials have a realisable slot counterpart; an example is the unipole.

The radiation pattern of a rectangular slot is similar to that of a dipole but the radiation is horizontally polarised where that of the dipole is vertical. Similarly the radiation vector for the annular slot is perpendicular to that of the equivalent loop aerial. The slot aerial normally radiates on both sides of the conducting sheet but the radiation on one side can be suppressed by surrounding the slot with a conducting box on that side.

The radiation resistance of a slot aerial is inversely proportional to that of the dipole. The half wave centre fed slot radiating on both sides has a resistance of 485 ohms which is doubled when the radiation from one side is suppressed. Although these values are high compared with cable impedances, successful matching can be achieved. One method is by a probe extending into the cavity behind the slot and having its axis parallel to the electric vector which is across the slot width. Alternatively off-centre direct feeding can be used, or the impedance can be reduced by means of a folded slot. This requires an isolated metal strip in the slot parallel to the long sides; the transmission line is connected between it and one side. The folded slot is analogous to the folded dipole familiar in television

aerials but, unlike the latter, has a reduced impedance. This is to be expected from the inverse relationship between slot and dipole.

4. The Effect of Adjacent Structures on Aerial Performance

The characteristics already discussed are for aerials operating under theoretically perfect conditions. In practice these conditions are rarely realisable, particularly in aircraft radio. These ideal circumstances will be used as reference in the consideration of practical results and will be known as "free space conditions".

4.1. RADIATION PATTERN

The simplest aircraft aerial is a unipole mounted normally to a flat conducting sheet or ground plane; when the plane is infinite in extent in all directions no signal exists on the shadow side and the maximum amplitude is in the plane of the sheet. As the dimensions are reduced the currents in the sheet no longer become zero at its edges. These currents give rise to secondary radiation with resulting signal on the shadow side of the sheet. Fig. 6 shows some patterns calculated for sheets of various diameters and it will be seen that the maximum signal strength no longer occurs in the plane of the sheet. The radiation pattern of a unipole on an aircraft fuselage is of this form along the axis of the fuselage and it is clear that if the main aim is ground-to-air communication, the best place for the aerial is on the underside of the fuselage so that the maximum radiation is downward. If, however, the fuselage is not many wavelengths long the penalty for putting the aerial above it is not too severe. The radiation pattern falls to zero at right angles to the fuselage but, as such large angles of depression only occur when the aircraft is close to the ground station, the effect is not serious. In any event the radiation from a vertical aerial on the ground will also fall to zero in the vertical direction, so that there would theoretically be no signal here whatever the aircraft

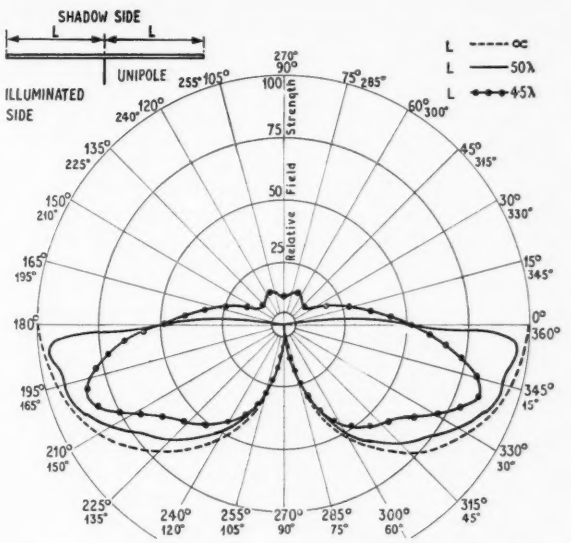


FIGURE 6. Radiation patterns of unipole aerials on finite sheets.

radiation pattern. In practice there is often sufficient horizontally polarised radiation from both ground and air to give satisfactory communication.

The vertical aerial on a ground plane is the simplest combination of the two components. When the aerial is not based on the plane but is some distance above it, the resulting radiation pattern is a combination of reflection and diffraction effects. The effects of reflection are shown by replacing the system by an aerial and its electrical image an equal distance below the ground plane. The resulting pattern has a number of maxima and minima at angles of elevation determined by the separation in wavelengths between the two aerials. An example of this is a vertical unipole

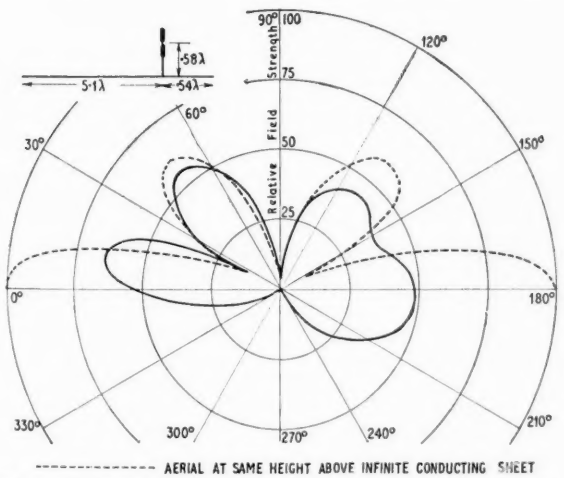


FIGURE 7. Radiation pattern of vertical aerial above aircraft fuselage (theoretical).

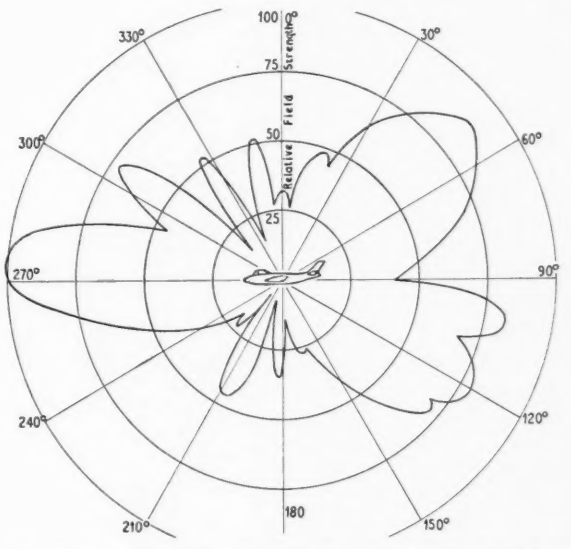


FIGURE 8. Fore and aft elevation diagram of vertical aerial on fin tip.

at the top of an aircraft tail fin. The elevation pattern is proportional to

$$\cos\left(\frac{2\pi}{\lambda} h \sin A\right)$$

where h is the height of the aerial above the fuselage and wings and A is the angle of elevation. Fig. 7 shows such a diagram in which both reflection and diffraction effects occur. This theoretical construction does not always hold: if the tail fin has dimensions comparable with, or less than, the wavelength there will be substantial currents on its leading and trailing edges. These will also radiate so that the resulting elevation pattern is that due to a number of vertical dipoles one above the other and their images. Such an effect might occur in the 100 Mc/s. region on a fighter or somewhere within the Gee frequency range on a large air liner or bomber. The resulting pattern could only be determined experimentally as the relative phase and amplitude of the secondary radiators would be difficult to calculate. Fig. 8 illustrates this effect as it shows experimental results for the aerial of Fig. 7, in contrast to those obtained from the simple theory.

So far only plane reflecting surfaces have been considered. When an aerial is mounted on a cylindrical surface the transverse radiation pattern will be determined by the relative radius of the cylinder. Currents flow round the circumference of the cylinder and produce patterns like those of Fig. 9.

A third class of reflecting surfaces includes other aerials and portions of the aircraft parallel to the axis of the aerial which is radiating. If a conducting element of substantially the same dimensions as the unipole is placed parallel to it and in close proximity, large currents may be induced in it, particularly if the element is grounded to the earth plane of the unipole and not more than a half wavelength from it. If the element is longer than a quarter wavelength, the

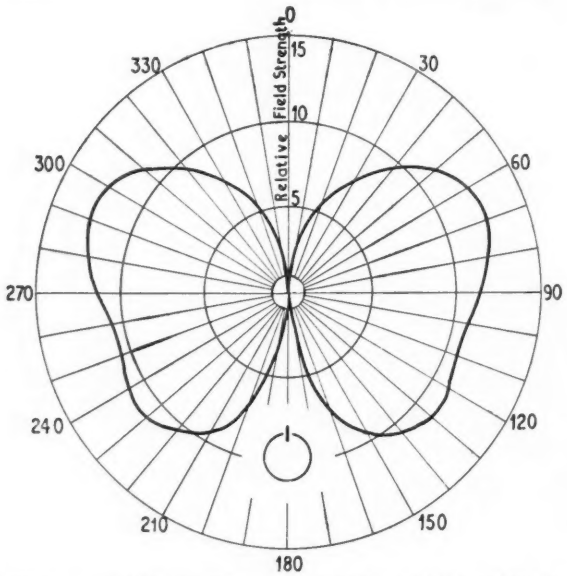


FIGURE 9. Radiation pattern of unipole on half-wavelength diameter cylinder.

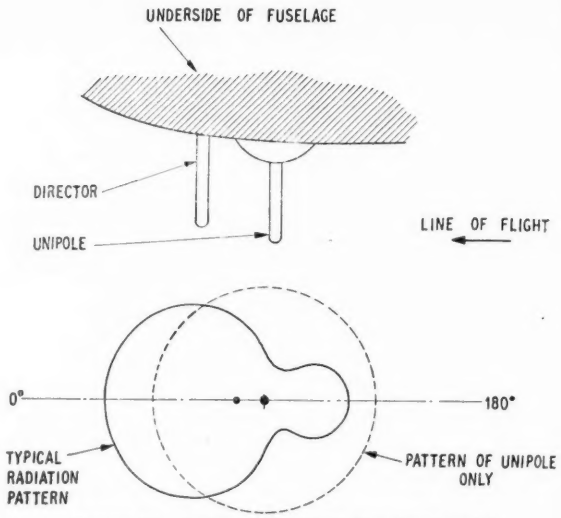


FIGURE 10. A simple 200 Mc/s directional aerial.

maximum radiation will be in the direction away from it and the parasitic radiator is then known as a reflector. If the element is shorter the maximum radiation will be towards it and it is known as a director. Such parasites are deliberately used to modify the radiation pattern as required. A familiar example is the Rebecca transmitting system consisting of a unipole and director arranged to give improved forward radiation (Fig. 10). It should be noted here that a distortion of the radiation pattern implies a gain in some direction since the total radiated power remains constant.

This parasitic effect must influence the separation of aerials which are not intended to inter-act. In general, aerials on the same frequency band should not be closer than one wavelength if trouble is to be avoided.

Diffraction patterns due to streamlined obstacles, such as tail fins, are shown in Fig. 11. The effects are least when the aerial is most distant from the obstacle and when the latter has small dimensions. If the obstacle is normal to the aerial, instead of parallel to it, the disturbances are greatly reduced.

The conclusion that can be drawn from this study of radiation problems is, in short, that theoretical considerations can be a very useful guide when the conducting surfaces are either very large or very small in terms of wavelengths, but that in the intermediate region there is no alternative to experiment based on experience.

When the aircraft dimensions are comparable with the wavelength the current is distributed over the whole structure and the radiation pattern is largely determined by the aircraft shape. It is impossible to dissociate an H.F. aerial from the aircraft and any such aerial can be considered as a means of energising the aircraft, which is the main radiator. Methods of making the aircraft most efficient as an aerial are considered in Section 5.

One other effect is confined to aircraft with propellers. At wavelengths comparable to the propeller length, aerials near them may induce appreciable

currents in the propellers. As these rotate the resulting aerial pattern varies in synchronism. This phenomenon is known as propeller modulation and may be serious in directional aerial systems such as Rebecca or I.L.S. The effects are rather different on these two equipments as Rebecca is sensitive to amplitude variations, while I.L.S. is only affected if the propeller frequency approximates to the audio modulation frequencies, which are 90 c.p.s. and 150 c.p.s. The only cure for this trouble is proper siting of the aerials sufficiently far away from the engines to minimise the effect.

4.2. IMPEDANCE

The impedance of a quarter wave aerial above an infinite ground plane is approximately half that of the equivalent half wave aerial, but the impedance will be largely dependent on the extent and shape of the ground plane when the latter is finite. As an example of an aerial on varying surfaces the familiar V.H.F. communications whip aerial may be considered. This might be installed on an aircraft fuselage, near a wing tip, on a tail boom (Vampire type of aircraft) or even on a delta tail fin. In each of these positions the impedance characteristic may vary widely, yet all are suitable places for such an aerial.

Parasitic aerials used in directional systems have a very marked effect on aerial impedances. Length, spacing and diameter of the parasites are all critical and the design of a system using them can only be a matter of patient experiment.

The impedance of a slot in a conducting sheet will be affected by the size and shape of the sheet to much the same extent as the unipole. Neither the slot nor the unipole can exist without the ground plane, a fact which is sometimes ignored in installations on non-metallic portions of aircraft and which no doubt accounts for some results obtained. A parasitic slot may be used in the same way as a parasitic dipole; in fact, in installing aerials on tail fins care must be taken to avoid parasitic radiation from gaps between fin and rudder. Such gaps may act as slots if the distance between successive hinge points is near a half wave length, but the effect can be overcome by suitably-placed bonding strips.

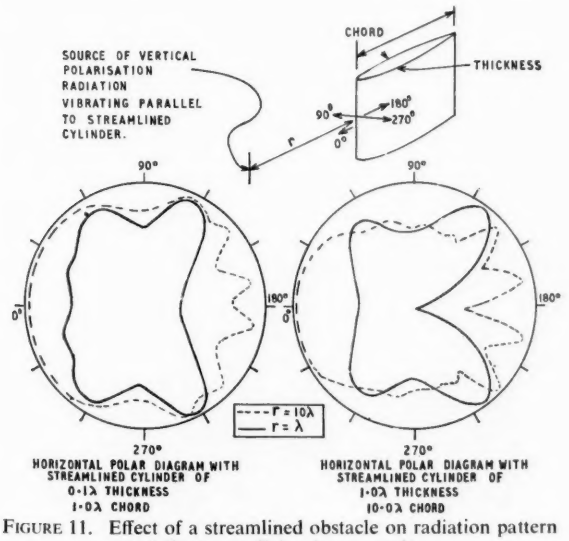


FIGURE 11. Effect of a streamlined obstacle on radiation pattern of dipole parallel to its own axis.

The impedance curve for a dipole shown in Fig. 2 refers to an aerial of very thin elements. By increasing their diameter this curve can be altered appreciably; the rate of change of reactance and resistance is decreased and hence for a given standing wave ratio a wider frequency band can be covered. The decrease in resistance at the first resonance is not large, the minimum practical value being about 60 ohms. At the second resonance, however, the resistance may be reduced from thousands of ohms to the order of 200 ohms.

The elements of a dipole need not be cylindrical nor even circular in cross section. Elliptical or streamlined sections may be used and may taper from the centre or, towards it. A dipole of the latter form is known as a biconical aerial and has the widest bandwidth of the various possible shapes, all of which obey impedance laws dependent on their geometry.

5. H.F. Aerials

Regarded as an aerial, an aircraft is an extremely complex one. The fuselage and tail fin may be considered as one dipole to which are attached two others, the wings and tail planes, at arbitrary positions electrically. Each of these separate dipoles will have its own impedance characteristics which will be different from those of the other two, so that the combined effect of all three cannot be readily computed. Where the tailplane span is not greater than, say, a quarter of a wavelength, it can probably be regarded as modifying slightly the fuselage dipole. The radiation pattern would then be that of a pair of perpendicular dipoles appropriately energised and the radiation pattern can be circular. When, however, the tail span is a half wavelength, the fuselage and wings may be up to $1\frac{1}{2}$ wavelengths and the resulting pattern may have several lobes whose position and size vary rapidly with frequency. An aircraft of 150 ft. span, 125 ft. fuselage and 50 ft. tailplane would have fundamental resonances at 3 Mc/s., 4 Mc/s. and 9 Mc/s., so that over the whole H.F. band complex patterns would be expected.

Early H.F. aerials of the trailing wire type attempted to use the aircraft as a counterpoise, but this is hardly a satisfactory practice and this type of aerial has almost disappeared. The fixed wire aerials which replaced them were based on a similar line of thought and, although many give adequate performance, they are at best inefficient radiators. One explanation of their operation currently accepted is as means for feeding the aircraft fuselage itself. The long wire slanting from nose to fin tip can be regarded with the fuselage as a transmission line which, because of its wide spacing, tends to radiate appreciably. This radiation may well have, through destructive interference, a low amplitude in the azimuth plane, hence the inefficiency of the

system. On this argument a better arrangement would be to make part of the fuselage plus a long wire act as a true transmission line to feed the remainder of the fuselage and the wings. This can be done by bringing the wire to within a few inches of the skin and letting it extend from one end of the fuselage for about one-third to one-half the total length. Such a system was first proposed by Mr. N. G. Anslow of Standard Telephones and Cables and results so far obtained have been very good. Some further work remains to be done before this method is capable of general application.

Several attempts to energise the aircraft have been made and some of these are described in the section on suppressed aerials. One such system, which has unfortunately only met with partial success, is the suppressed coupling coil put forward by W. A. Johnson of the Royal Aircraft Establishment. It is well known that the maximum current density in a non-circular conductor is at the points of greatest curvature, which in an aerofoil correspond to the leading and trailing edges. A coil placed near these should be able to couple energy into the wing or tail plane and, although the coupling is not very great, there should be sufficient radiation to compare with that of a conventional fixed wire aerial. While some good results have been obtained it seems that the position and engineering of the coil for best results are rather critical and the method may not always be practicable because of the aircraft size and structure. Various methods of providing an H.F. aerial are shown in Fig. 12.

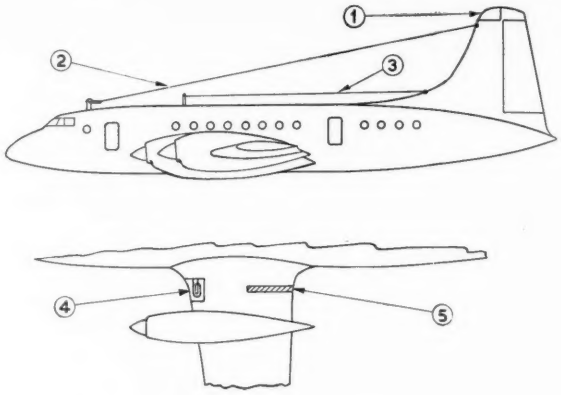
The last mentioned aerial should not be confused with the loop aerial used for L.F. direction finding. This is a small multi-turn coil wound on a high-permeability core to improve its sensitivity and mounted centrally above or below the fuselage. The figure-of-eight radiation pattern is used to determine the direction of a ground station, the loop being rotated until a minimum is obtained. The output of the loop is combined with that of a sense aerial to resolve the ambiguity, the resulting pattern having only one minimum instead of two. At these low frequencies the effect of the aircraft on the radiation pattern is comparatively small and the errors arising can be allowed for on the bearing indicator.

6. Mechanical Aspects

This facet of aerial design can best be illustrated by reference to one particular type:—a quarter wave unipole mounted above the fuselage of an aircraft in the best position as regards radiation pattern. To get the best bandwidth a conical aerial element might be used which was supported at its base with the minimum possible amount of insulating material; this material would have the best possible electrical characteristics—high electrical strength, low dielectric constant and low loss, in particular low water absorption. Such materials as polythene, glass and ceramics would satisfy these requirements but would be quite unsuitable mechanically.

6.1. AERODYNAMIC FORCES

In flight two aerodynamic forces act on an aircraft



1. INSULATED FIN TIP.
2. LONG WIRE AERIAL
3. WIRE AS TRANSMISSION LINE.
4. SUPPRESSED COIL.
5. NOTCH FEED.

FIGURE 12. Methods of exciting an aircraft structure at H.F.

aerial. These are its resistance to motion, or drag which operates in the line of motion and its lift or side load. The term lift is strictly applicable only to structures having asymmetry about a horizontal axis, while side-load applies to vertically-asymmetric surfaces, but both are forces acting normally to the line of motion and caused by differential air velocities over the asymmetric surfaces. With a vertical unipole the drag and side load will be distributed along its length but can be considered to act at a point and will produce a bending moment at the root of the aerial. Either the aerial may bend under these forces, or it must be made sufficiently strong to remain rigid and unbroken under its operating conditions. The forces acting are dependent on the shape of the aerial and are proportional to the square of the air velocity up to speeds of a Mach number of about 0·6, after which they increase much more rapidly up to the speed of sound.

For the same frontal area the aerial of circular cross section has a higher drag than that of any other practical shape, the cross section of least drag tending towards a diamond or elliptic shape with major axis parallel to the direction of flight. For low air speeds the optimum streamlined shape has a rather blunt nose and a chord to thickness ratio of perhaps 3, but as the air speed increases this ratio has to be increased to the order of 10 or 12. Aerials of circular cross section are usually made thin to minimise their drag, which is further reduced if they can bend in flight. Such aerials are known as whip aerials. They are made of high tensile steel rod and have been made as long as 6 ft., although they do not often exceed 3 ft. 6 in. today. Sword aerials are those of streamlined section, rigid in form and rarely exceeding 27 in. long. They may be solid, or steel, or light alloy, depending upon their size, or of a thin metal shell upon a wooden or plastic former. Both sword and whip aerials are generally tapered to reduce drag, whip aerials in a number of parallel sections of decreasing diameter for purely economic reasons. Some typical unipoles are shown in Fig. 13.

6.2. VIBRATION

If drag and side load were the only forces acting on an aerial there would be no great difficulty in making one strong enough to stay on any aircraft, however fast. Whip aerials are being quite successfully flown at speeds up to Mach one and have been considered satisfactory up to a Mach number of 1·5 under some conditions. One other problem is that of vibration. Every aerial has a number of natural mechanical resonances at frequencies determined by its shape and method of construction and these may be excited in several ways. One of these is by mechanical vibration of the airframe and is particularly prevalent in piston-engined aircraft. Some portions of the aircraft will have higher exciting amplitudes than others; in particular the extremities of wings and empennage are areas of relatively large vibration as are, of course, the power units themselves. Should these vibration frequencies coincide with the aerial's natural frequency for any length of time, breakage of the aerial will eventually occur through fatigue. Aerial vibration may also be aerodynamically excited with similar unfortunate results. In particular the formation of ice on an aerial may so alter its shape as to make it very prone to vibrate; this form is known as icing flutter. Tendency to vibrate may be reduced by raking the aerial, but this may be undesirable electrically as it alters the polar diagram and impedance, in general decreasing the useful bandwidth. One other remedy recently introduced for whip aerials is the anti-vibration mounting.

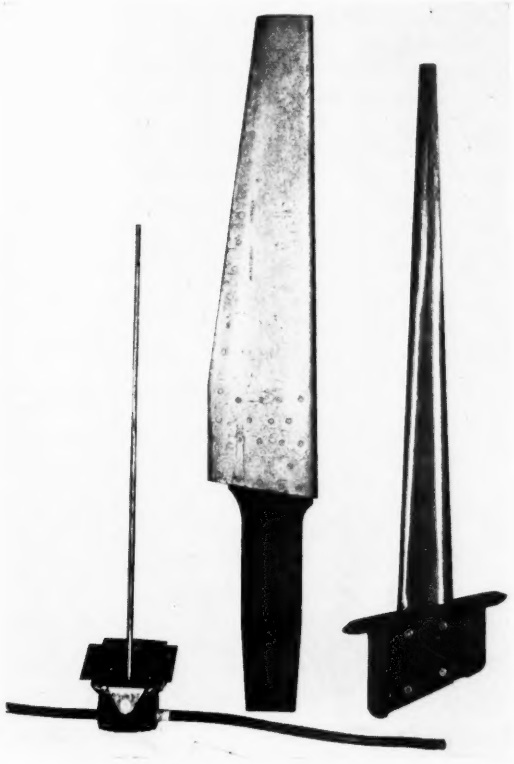


FIGURE 13. V.H.F. sword and whip aerials.

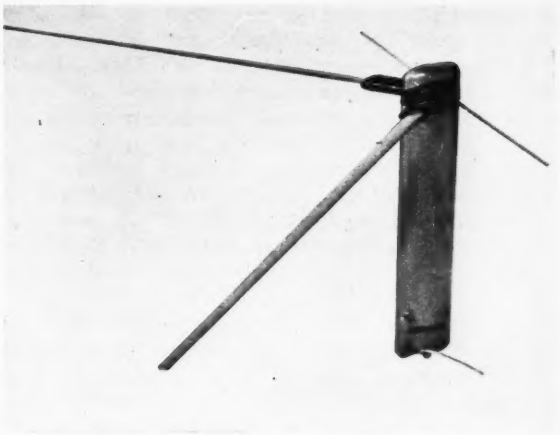


FIGURE 14. A pedestal mounted vee dipole.

This allows the aerial to rock a few degrees transversely against a damping agent and thus diminish the energy of vibration.

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6.3. THERMAL EFFECTS

Another effect to be borne in mind is the aerodynamic heating of the skin which occurs at high speed. The insulators of external aerials must be made to withstand these rises in temperature, and also the very low temperatures which may exist under some conditions, without appreciable loss of strength.

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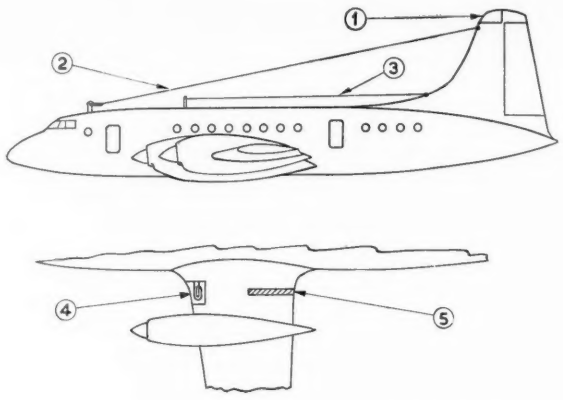

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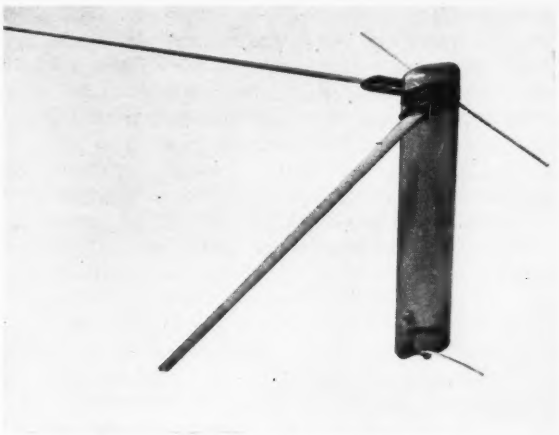

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products. These are synthetic resin bonded sheet, phenolic mouldings, glass fibre laminates, resin bonded asbestos laminate and acrylic resins. These do not differ substantially in electrical properties, at least up to 100 Mc/s., but have somewhat different uses determined by the form in which they are available.

The moulding materials are usually reinforced by the addition of a filler, such as nylon, which improves their mechanical properties, especially shock resistance, but also increases their water absorption. Mouldings will normally only be used where they are of general application and can be produced in large quantities, *i.e.* the base of whip aerials.

The other materials find more varied uses as aerial covers, supports and mountings. The laminated glass fibre and asbestos can be made up into complex forms, such as fin and wing tips and nose caps and possess the advantage that local variations of thickness can be made where required. Acrylic resins can be formed into many shapes and are as adaptable as the laminates, but with much lower strength to weight ratios. The synthetic resin sheet has to be machined to shape and is therefore more limited in application than the laminates, but it can rival moulding materials.

Their high tensile and compressive strengths make the glass-fibre materials very attractive structurally. Some disappointments have occurred electrically through insufficient care in specifying the exact construction of the laminate. In particular water absorption can be troublesome unless the glass cloth is chemically treated before bonding to ensure complete flow of the resin into the fibres. When this has been done, stable products can be obtained which should be as good as any of the other materials available. The

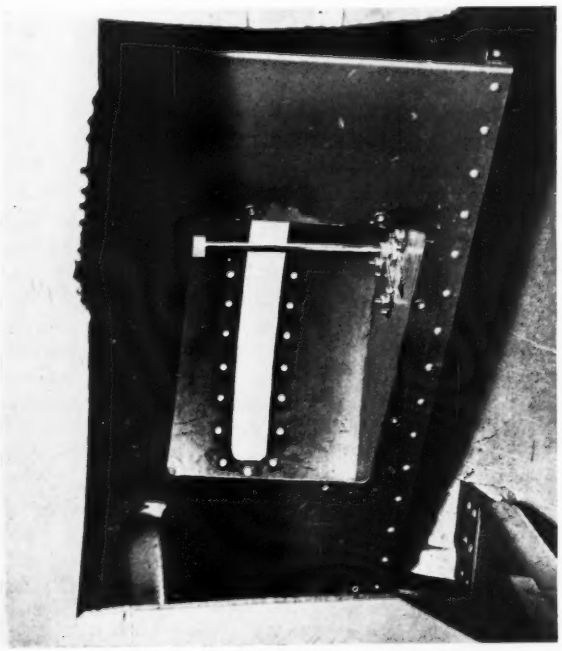

FIGURE 15. A suppressed slot aerial.

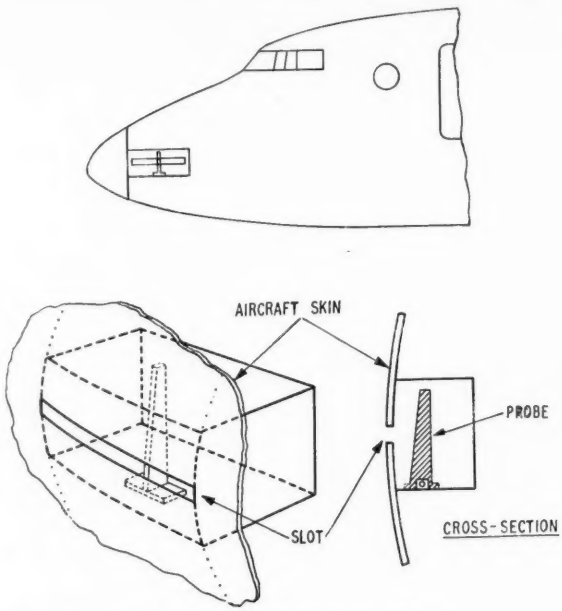

FIGURE 16. Homing aerial for Rebecca.

glass-fibre laminates are largely employed for radomes because of their high strength, but here they are used in combination with other materials in sandwich constructions. These usually consist of two thin skins of glass cloth separated by a core of low density dielectric; expanded rubber, foamed Perspex and polythene have been used here. The exact dimensions of the sandwich are extremely important in ensuring the best transmission at centimetric wavelengths.

All laminates suffer to some extent from rain erosion. That is, rain drops driven at high velocity against surfaces normal to the line of flight gradually penetrate the layers and cause peeling, with eventual disintegration. Neoprene carefully applied to the outer surfaces can largely prevent this trouble but the emphasis must be on careful control of the processes involved. A furane treatment for asbestos laminates has also proved successful, but this material is not so satisfactory electrically as the glass cloth products and should not be used above the V.H.F. band. It is possible that bonding Perspex or polythene on to fibre glass might overcome rain erosion problems.

Where mechanical strength is less important than electrical quality, polythene and p.t.f.e. are used. The latter has better high temperature characteristics but is as yet only in limited use because of its high cost. One disadvantage of polythene is that its chemical inertness prevents it from being bonded to other materials; this makes sealing a problem unless the moulding can be designed to take advantage of the natural shrinkage of the material on cooling.

8. Suppressed Aerials

In discussing mechanical requirements it has been assumed that the aerials are external and their design has been treated on this assumption. It is possible to

meet the electrical specifications for some aerials when they are enclosed within the envelope of the aircraft. Such arrangements are known as buried or suppressed aerials.

8.1. SLOT AERIALS

Slot aerials are one form of suppression successfully used when limited radiation coverage is required. Fig. 15 shows a vertical slot in an aircraft nose; this aerial gives horizontally polarised radiation in the forward hemisphere and is used for I.L.S. glidepath reception. The Rebecca homing aerial shown in Fig. 16 is one of a pair symetrically disposed about the aircraft axis and used to provide mirror-imaged directional patterns with vertical polarisation. The length of the slot and cavity is, in each example, about a half wavelength at the lowest frequency required. Smaller slots can only be used where very small frequency bands are needed. This dependence of dimensions on frequency fixes a practical lower limit for slot aerials at about 200 Mc/s., where a slot length of about 27 in. is necessary.

8.2. FLUSH-MOUNTED UNIPOLES

It is possible to use a dipole or unipole set flush with the aircraft skin as a directive suppressed aerial. Such a system has maximum radiation normal to the aerial and minimum along its axis. If the conducting surface in which the aerial lies does not extend more than about one wavelength in each direction along the axis, the ratio of maximum to minimum field strength does not exceed about 3. By combining two such aerials in the proper phase a substantially circular radiation pattern can be obtained. A satisfactory arrangement depicted in Fig.17 is used for V.O.R.and I.L.S.localiser. The aerials are mounted on either side of a cavity extending through the aircraft fin but divided by a central diaphragm. This system is typical of many in having the aerials shunt fed, that is, the base of the aerial is connected to the ground place and the cable is attached at some point along the aerial. Shunt feeding is essentially a narrow-band device and therefore of limited application. It has one advantage in not requiring an insulator at the base of the aerial and it also gives a second variable factor to assist in impedance matching. It is advisable for the aerial element to be separated from the dielectric covering it to minimise variations due to rain on the cover and water absorption. Shunt feeding is also used for suppressed I.L.S. glidepath aerials and marker aerials, one of the latter being shown in Fig. 18. Since a half wavelength at 75 Mc/s. is 2 metres, considerable shortening is necessary to make the aerial a practical size. This is possible by substantial capacity loading, the aerial element being only 16 in. or one-tenth of a wavelength. Such short aerials have practically constant current along their length and their gain is directly proportional to this dimension.

8.3. VERTICAL AERIALS

Vertically polarised aerials to give all round azimuth coverage can be suppressed in two ways. One of these is by the annular slot aerial mounted in a horizontal conducting surface, *i.e.* the upper or lower surface of fuselage or wings. Since for any useful bandwidth the diameter of the aerial must be about 0·7 wavelength, the lowest practical frequency is about 500 Mc/s. This type of aerial is used in the 1,000 Mc/s. band but has not so far been employed otherwise.

The alternative method is to place the aerial within the aircraft fin tip in a suitable dielectric cover. Advantage can often be taken of the space available to make really wide band aerials by shaping the elements. The possible configurations are too many to discuss in detail but one which illustrates another application of shunt feeding is depicted in Fig. 19. This type is known as a notch-fed aerial. A segment is removed from the metal fin tip for a distance of about a quarter wavelength and the gap thus formed is covered with

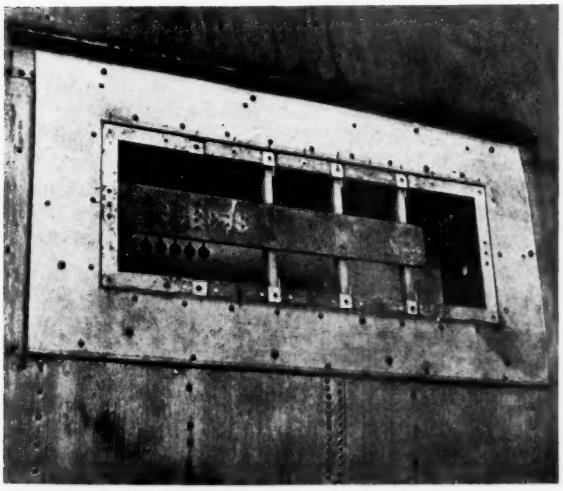

FIGURE 17. Suppressed I.L.S. localiser aerial.

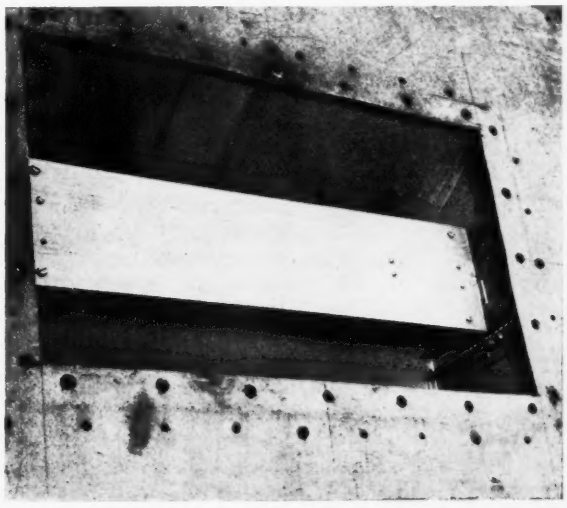

FIGURE 18. Suppressed I.L.S. marker.

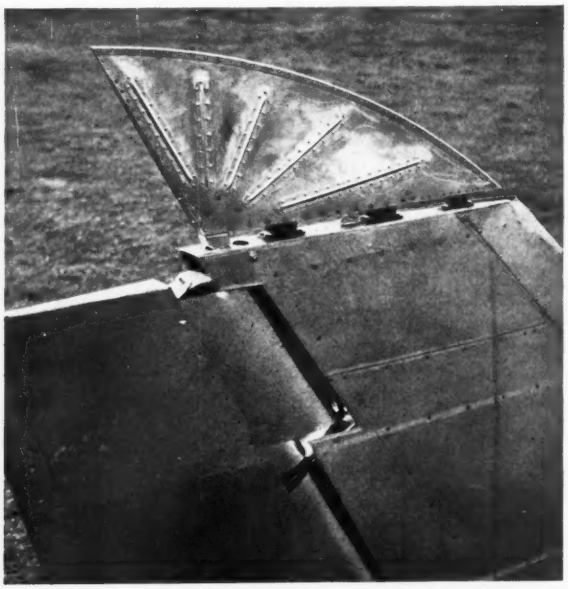

FIGURE 19. Shunt fed V.H.F. fin tip aerial.

FIGURE 20. Tower for aircraft model work.

dielectric. The inner of a coaxial cable extends across the gap at a point chosen to give the best impedance. The sides of the notch are here parallel, but for the widest bandwidth they should taper exponentially outward. Mechanically this aerial is good for it has the property that, provided the tip chord does not greatly exceed one wavelength, the remainder of the tip can be metal without detracting from its electrical performance. The faces of the notch can be bridged by dielectric if additional strength is required, but this may be unnecessary if the cover is made sufficiently robust. Where very small bandwidths are required the notch can be shortened and loaded with capacity across its open end.

8.4. H.F. AERIALS

Suppressed aerials for H.F. and the lower end of the V.H.F. band may take the form of insulated wing or fin tips, or even a large proportion of the tail fin. Structural considerations must determine what is practicable in this field but it will rarely be possible to obtain other than short aerials with narrow inherent bandwidths. Such aerials require tuning units adjacent to them and unless such units are fully remotely controlled, their inaccessibility may deter their would-be users. When the aircraft's length is of the same order as the wavelength it will be found that radiation will not be confined to the isolated portions we have mentioned, but the whole structure will act as a complex dipole system fed near one end. The effects of tail planes and wings cannot readily be calculated and it may only be possible to evaluate such an aerial system in flight. The notch method can be applied to H.F. aerials, preferred positions for the notch being the wing or tail fin root. Tuning units are necessary to resonate and match the notch over the wide frequency bands required.

8.5. S.H.F. AERIALS

At the other end of the frequency scale are the various scanning devices used for precision position indication. Essentially these consist either of a dipole or waveguide feed to a shaped reflector, or of an array of dipoles or slots arranged to give a narrow beam. Such systems demand an unrestricted view in their field of operation and must, for protection and aerodynamic reasons, be enclosed in electrically-transparent envelopes, the construction of which was considered in Section 7.2.

Suppressed aerials are not in themselves a universal recipe for happiness on the aircraft designer's part. They may reduce the drag and improve the beauty of an aircraft but often at the cost of structure weight increased out of proportion to the other savings. They often have to be tailored to each aircraft and may therefore have a high development cost, even if production costs are low—which they rarely are in comparison with external aerials produced in quantity. Liability to breakage is reduced by suppression but in its place come problems of finding satisfactory dielectrics for covers, problems which are by no means answered yet. The suppressed aerial may often be so much a part of the aircraft structure that adjustment or replacement is very costly, if not impracticable. It is debatable whether a "fit and forget" policy is possible yet; impressive totals of trouble-free flying hours are, however, being logged on some suppressed aircraft aerials. In short, the decision to suppress should be based on an understanding of the advantages and disadvantages of so doing, rather on a desire to be in the fashion. It must be based on sound co-operation between aircraft manufacturer or operator and aerial engineer, for it is essential that the latter should be brought in as soon as the aircraft has reached a sufficiently defined form for

discussion. It should be noted, too, that any change in equipment requirements may cause considerable revision in aerial positions already determined.

9. Design Procedure

Several distinct steps in the design of an aerial emerge from the foregoing remarks. First, the probable form of the aerial is dictated by its electrical requirements and its position on the aircraft is suggested by these and by the shape and structure of the aircraft. It may be necessary at this stage to build simple forms of the aerial to study its properties generally and to see the effect of modifying its parameters. Next, its position and performance can be confirmed by measurements, either on the aircraft, if available, or on a model. The use of scale models is in its infancy in this country but is rapidly proving its worth.

The model range developed by R.A.E. is an example of this type of work. Aircraft models whose scale may be between one-tenth and one twenty-fourth of full size are supported at the top of a non-conducting tower so that they are effectively in free space. The models are usually wooden and covered in copper foil (spray has been used but is less durable) and are made hollow to reduce weight and to contain test gear. The R.A.E. models contain battery-operated transmitters whose frequencies are scaled up in the same ratio that the models are scaled down, *i.e.* a one-tenth scale aerial measured at 1,000 Mc/s. represents 100 Mc/s. full scale. The models can be set in various attitudes and can be rotated so that the radiation pattern in any plane can be measured. The signals received at a fixed aerial remote from the model are automatically recorded and the results from measurements in different planes can be combined to make a solid radiation figure which is a complete picture of the radiation from the aerial at that frequency. If a wide band is to be covered, measurements at several frequencies will be necessary. Fig. 20 shows one form of tower in which the model is mounted on a horizontal arm about which it can be rotated, while the tower itself can turn about a vertical axis. By using appropriate rotations a complete set of plane diagrams can be obtained.

Model work can only yield information on radiation patterns and impedance measurement must be done on full-sized sections of aircraft. In general the section must extend at least a half wavelength around the aerial and for aerials on tail fins and wing tips it is usually necessary to provide larger portions to avoid end effects. Since only the envelope of the aircraft is important, these sections are usually built as wooden frameworks covered in sheet metal or fine mesh. The immediate vicinity of the aerial must be carefully modelled and dielectric covers provided.

If the preceding stages have shown the proposed aerial to be suitable and if, as does sometimes happen, the manufacturer has not changed the shape of his aircraft in the interval, the installation can proceed and eventually further measurements can be made on the completed aircraft. These will include impedance and radiation pattern measurement in the azimuth plane. Not every aerial can be usefully measured on a grounded aircraft; H.F. aerials provide only limited information, as do any aerials mounted under the fuselage where proximity to the ground nullifies the measurements. Nevertheless many V.H.F. aerials can usefully be checked on the ground and in straightforward installations on existing aircraft these may be the only measurements necessary, or possible, before flight testing.

The last stage is the most expensive and should be kept to the minimum consistent with proving the installation. Measurements of ultimate range can often be combined with other flight tests and unless previous stages have shown gaps in the radiation patterns, tests of these in flight should not be necessary.

10. Conclusion

This lecture can be, at best, an introduction to a vast subject, an outline of the why and wherefore of aircraft aerial design. More detailed treatment of the topics discussed can be found in the published work of W. A. Johnson[1] and R. H. J. Cary[2,3] in this country and J. V. Granger[4] and G. Sinclair[5] in America, to name only a few of those who have been active in this field.

11. Acknowledgment

This paper is published by the permission of Standard Telephones and Cables, to whom the author's thanks are due. He also wishes to acknowledge that Figs. 6 and 11 were adapted from Ministry of Supply publications.

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Plastics Structures

by

G. C. HULBERT, B.Sc ,

(Polyester Technical Service, Scott Bader & Co. Ltd.)

1. Introduction

More than two years ago Pollard[1] in a paper given to the Society made out the case for the use of fibre-reinforced plastics in the structural field. He and others have shown that materials based on strong, inert fibres, such as glass or asbestos, have mechanical properties which, when stabilised by suitable resins, permit them to function with a high degree of efficiency within certain well defined parameters of loading.

Four distinct groups of resin are used in combination with such fibres, phenolic, polyester, epoxide and silicone. With the present exception of silicone resins, each can be used at low or even contact pressures during moulding and thus do not impose serious processing limitation upon the size, quantity or complexity of the structures which can be contemplated.

In addition to their mechanical and manufacturing possibilities, individually these materials possess certain valuable secondary properties. It was by making use of such properties as radar transparency that their use was first established. Such use continues to the present time and in fact still constitutes the reason for adopting the material in the majority of existing applications.

The growth of structures making use of the mechanical properties for important load bearing applications has been slow, despite the courage of certain companies who have built important prototypes, such as complete wings, which have undergone searching tests with reassuring results.

The serious use of any material is bound to be proportionate to the confidence which can be placed in it. It is the intention of this paper therefore to examine the experience and knowledge of the material, to isolate, if possible, some factors which hinder this necessary growth of confidence and, where possible, to offer encouragement to those, who, like the author, believe in the ultimate valuable service of which the material is capable.

2. Factors

Within the scope of a single paper it will not be possible to examine all the factors, the study of which could help to further the use of the material. The author has therefore chosen the following four for consideration. They have been chosen firstly because of their immediate importance to the position and secondly, because it is felt that a state of knowledge has already been reached where something immediate and constructive can be done about them. They are: —

1. Consistency of test results and its effect upon the design safety factor.
2. Permanence of behaviour when exposed to weather and other normal external agencies.
3. Fatigue and creep behaviour.
4. Temperature resistance.

3. Consistency of Test Results

Plastics materials, particularly those containing reinforcement of glass or asbestos fibres, have unfortunately gained a reputation for a high degree of scatter in test results. So long as this persists designers will suffer the handicap of a high safety factor in their designs. At present this is approximately double that operating for metal structures and largely nullifies the strength/weight advantage the material has over its competitors. It must be ascertained therefore whether this scatter is inherent in the material or whether it is due to the treatment of it either in manufacture, processing or in testing. Fortunately the experience of at least one large company indicates that scatter inherent in the material is neither more nor less than in any other and that, once correct and full control of treatment has been established, its mechanical behaviour is fully consistent. Correct and full control of treatment would therefore seem to be the key and it is necessary to ascertain what this involves.

It must first be realised that in producing a moulding of reinforced plastics material we have largely telescoped into one moulding operation many factors which, in metal it would have been possible to control and test at various clearly defined stages such as foundry, rolling mill and finally fabrication of the raw material into the component. Further, that it is impossible in the reinforced material to find a true equivalent to the raw material stage for a metal sheet. Reinforced plastics is not a single homogeneous material but, even in a simple test piece, is a structural alliance of two dissimilar components. It is therefore obvious that all factors in the make-up, handling and processing together of the glass, asbestos or resin can affect the final behaviour of the structure. Only now is a state of knowledge being reached when it is possible to recognise the factors and to select those which can be regarded as key factors, the control of which will ensure consistent behaviour of the final product.

At this point a comparison between the state of knowledge about the asbestos-reinforced phenolic materials and the many combinations of glass fibre and resin is of interest.

With the asbestos phenolic resin materials a limited number of forms are available, two or, at the most, three

*A Section Lecture given to the Royal Aeronautical Society on 3rd May 1955.

CURING BEHAVIOUR IN POLYESTER RESINS

TABLE I

Maturing time of Laminate at 20°C. (days)	5 *hrs.*	1	2	3	5	10	18	55
Laminate made with Resin A 2 per cent. Cyclohexanone Peroxide 0·016 per cent. Cobalt	1	3	4	4	5	15	75	180
Laminate made with Resin B 2 per cent. Cyclohexanone Peroxide 0·016 per cent. Cobalt	420	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
Laminate made with Resin B 2 per cent. Cyclohexanone Peroxide 0·004 per cent. Cobalt	2	15	30	300	17 hrs.	22 hrs.	N.C.	N.C.

Time in minutes for 0·5 grams drill shavings to colour 10 ml. Starch/Iodide solution.

Note: N.C.—No Colouration.

being of practical interest to the aircraft fabricator. Because of the limited number of forms it is found that, thanks to the hard work by the Royal Aircraft Establishment and others, each has been tested exhaustively in the three characteristic pressure/temperature moulding conditions commonly employed. Authentic and reasonably complete strength and performance data have therefore been published and have been available to the designer for some time. Compare this with glass fibre.

One of the virtues claimed for resin-reinforced glass fibre has been the versatility, wide choice and control of the fibre pattern available to the designer. But as Welch[2] points out this wide choice has also had an adverse effect and has led to the trial and use of such a multitude of glass fibre and resin combinations that little or no comprehensive data exists about any individual one. This point cannot be too strongly emphasised and a serious plea is put forward that we voluntarily limit ourselves to a minimum of combinations which are structurally necessary, or which hold considerable promise if further developed. By attempting to evaluate too large a number of combinations it has also not been possible to gain the necessary experience to control the variables in the manufacture of each and this has contributed largely to the variability of results encountered by individual laminators.

With asbestos fibre-reinforced phenolic resins the main problem would appear to be in the production of resinated felts having full consistency of fibre content and orientation. Once this is achieved the conditions of temperature and pressure under which these felts are moulded ensure a good degree of consistency, due to the isolation during this time from ambient conditions which are known to influence laminates made at contact pressure and, more particularly in the case of polyester resins, where contact pressure is allied to curing at room temperature by means of chemical catalysts.

With all fibre-reinforced materials, just as for those based on asbestos fibres, the first need is for control over resin type and content, fibre content and fibre orientation before consistency can be expected or comparison of behaviour attempted.

For glass fibre polyester materials it is also necessary to control the fibre bundles so that their make-up and weave, (if present) is identical and it is also necessary to have full consistency in the type of textile size present, or method of desizing and type of "finish" treatment, if used. For the resin it is essential that the exact resin is specified and that the manufacturer can supply it with a high batch to batch consistency in make-up and behaviour. There must be careful control over the catalyst and accelerator or temperature used to effect the cure; any pressure used during this period must be controlled. The efficiency of impregnation must also be watched and any necessary post-cure heat treatment must be faithfully repeated on successive mouldings. Only when these main conditions have been met is it safe to start comparing the performance of mouldings. Remember too that the preparation of the test pieces and their method of being tested can also introduce variations into the results which are to be compared.

Far too often one sees results set out as "Strength of Polyester glass fibre laminates based on 0.009 in. square weave glass fabric so many pounds p.s.i." One is then surprised to see another worker claiming strengths for what appear to be identical materials which vary by as much as 30 per cent. from the first figure. Such comparisons are valueless since, by altering only one or two of the conditions mentioned, the two laminates may differ as widely as do aluminium and duralumin.

But even after strict control such as that already outlined has been exercised, there frequently remains a disturbing degree of variation among tests made even in the same works or laboratory. Much work has been carried out to identify the hitherto hidden factors causing these variations. Parkyn[3] in a recent paper given to the Society of Chemical Industry attributes much of this variation to the degree of stability reached by the resin at the time of test. He outlined four contributory factors, a study of which will show that stability can be influenced by agencies which remain as impurities or affect the degree of polymerisation of the resin.

As these factors are of great interest they are included in this paper together with the more interesting of the tables illustrating their effect.

TABLE II

"Undercured" Laminate	3·2	3·4	3·5
"Fully cured" Laminate	2·7	2·7	3·1

Average figures for "E" × 10^6 lb./in.^{2} measured on three separate polyester-glass laminates.

TABLE III

Time after Lay-up (hours)	½	1	1½	2	4	6	8	24
2 plies 0·009 in. square weave glass cloth	4·5	6·6	8·2	9·3	12·4	15·0	16·1	21·6
1 ply 2 oz. chopped strand glass mat	0·5	0·8	1·0	1·2	1·7	2·3	2·8	5·4

Percentage loss of styrene on resin weight due to evaporation at 20°C.
Resin content of cloth laminate 44 per cent.
Resin content of mat laminate 70 per cent.

(*i*) The complete absence of any residual free peroxide catalyst or other oxidising agent in the cured resin (*See* Tables I and II).

(*ii*) The absence of unreacted styrene or other monomer in the cured resin.

(*iii*) The absence of relatively low boiling compounds such as ester plasticisers. Dimethyl phthalate, for example, is frequently used as a carrier for either the catalyst or accelerator. This does not combine chemically with the resin and sometimes migrates out of the cured resin after a period of time.

(*iv*) The resin must be fully cured. This term is rather loose, particularly when applied to polyesters. (*See* Tables III and IV).

It is not intended to duplicate this paper but a few comments may be helpful.

The residual catalyst content, and particularly Table I, is important because it shows the very great difference in the maturing behaviour between resins. It is also of great importance since the resin manufacturer has now a means—something other than trial and error—to estimate the amount of catalyst to bring about the full reaction and upon which to base his recommendations for formulations. Too little may lead to expenditure of the catalyst before polymerisation can be completed. Too much may leave a permanent residue of peroxide which, due to its reactivity, may have a harmful effect upon the laminate later when it is able to combine with external agencies present during weathering. Table II is of interest because it shows how the properties of a laminate can vary significantly unless the resin has reached full maturity at the time of test.

Dealing with the second and third points the unstable presence of any material as an impurity in the resin will have an effect on its behaviour and rapid elimination, whenever the correct conditions happen to occur, will cause a change. Unless understood, this could give a misleading impression of instability in the laminate. It is very significant that all cold cured laminates subjected to heat post cure have noticeably more consistent behaviour.

Possibly of greatest practical significance in the fourth conclusion is the degree of styrene evaporation which can occur in laminates (Table III).

Hitherto unnoticed variations in workshop conditions such as still air or draughts, slight changes in temperature or change in surface area/volume ratio from component to component, can rapidly and significantly affect the amount of styrene lost. Beyond a certain point there may be insufficient styrene left to carry out its full cross linking function and it will therefore affect the behaviour of the laminate in a variety of ways. It can lower the thermal resistance, affect the modulus and undermine chemical resistance, to mention only a few of the possible results (Table IV).

It is also of interest to learn that, out of this work, the lack of fluidity in thixotropic resins has found a new and important use. The presence of thixotropic resin limits the styrene loss to the surface by preventing replacement and thereby effects a significant reduction (about 50 per cent.) in the overall amount lost.

Much more could be said on this topic but it is hoped that the foregoing will be sufficient to reassure all those who have been disturbed by the problem. As the causes are being successively isolated and brought under control, the inherent reliability of fibre-reinforced materials is being established.

4. Permanence of Behaviour

However successful we may be in controlling the manufacture of our mouldings to achieve initial consistency in behaviour, it will be of little use if such behaviour is not permanent. Alternatively, if some deterioration when exposed to normal agencies has to be accepted, then such deterioration must be shown to be finite and able to be forecast with certainty. Unless this is possible, no designer with any pretence to responsibility can be expected to make use of the materials in any structural application of importance.

Those materials deriving their strength from glass fibres would appear to cause the most concern in this connection. After an initial loss all combinations of asbestos and a resin appear to be reasonably stable. The very much higher strengths, particularly tensile strength, possible with glass fibres make it of vital importance that we make every effort to overcome this difficulty in materials based on glass fibre.

What then can be said of this most important problem? Tests on the resins and in particular

TABLE IV

Total Immersion (days)	1	2	4	8	18	29	86	241
1 ply 0·009 in. square weave glass cloth	1·79	1·09	0·56	0·22	−0·11	−0·35	−0·36	−0·45
1 ply 0·030 in. scrim weave glass cloth	1·38	1·41	1·25	1·11	1·03	0·78	0·77	0·55

Percentage change in weight of single ply laminates immersed in water. Upper face of laminate made exposed to air.

polyester resins have shown them, once fully matured, to be extremely stable under all external conditions which their chemistry permits them to resist. We can confidently say therefore that in the absence of active organic solvents, of strong alkaline or of oxidising acid conditions, the resin can be regarded as stable and inert. We are therefore led to the conclusion that the deterioration is mainly linked to the behaviour of the glass fibre in the laminate and that, in addition to its structural function, we at present ask the resin to protect the glass fibre from external influences.

Much has been said about this problem and at present the emphasis is upon finish treatments for the fibre permitting full adhesion of the resin to the glass. While admitting that developments in this field have shown a great reduction in the strength lost and a significant lengthening of the period over which these conditions can be resisted, we have not yet eliminated the problem. Megson[4] in a recent paper to the Institute of Marine Engineers makes a comment which is most relevant to this matter when he says:

> "Resin-reinforcement interaction is another topic which needs fundamental examination. The properties of a laminate are not necessarily simply related to the properties of the individual components. In this connection, it will probably be essential to study the properties of individual fibres with special reference to microscopic flaws and to undertake statistical analysis of the results of mechanical tests."

Although we have considerable knowledge about the behaviour of the fibres and resin much of it is empirical and far too little is fundamental. Jaray[5] has thrown some light upon the behaviour of glass fibres when subjected to corrosive attack but, as can be inferred from Megson's comment, we are not in a position to assume that what happens to either material in the absence of the other will necessarily be reproduced within the combination.

Similarly, despite the present emphasis on adhesion of resin to fibre, it is felt that we should not be too hasty in assuming that this is the complete or final answer.

Due to the lack of fundamental knowledge already mentioned it is difficult to make the contribution one would wish to this section of the paper, and in discussions with many others in the industry, it is clear that very little in our ideas goes much beyond conjecture.

All that the author feels he can usefully contribute is an attempt to summarise the position and to indicate possible lines of development.

It is first necessary to establish whether the deterioration which persists in "finish" treated glass fibres is due to the original adhesion being incomplete, thus providing an initial point for moisture attack, or whether the adhesion breaks down due either to normal thermal and attendant dimensional change, or to stress loading. If imperfect initial adhesion is the case then present work going on to improve the bond may alone provide a satisfactory answer quickly.

Should the bond be found good initially but showing subsequent breakdown then the following must be determined.

(*i*) Does the breakdown occur between resin and "finish" leaving the latter unable alone to prevent deterioration of the fibre?

(*ii*) Does the breakdown occur between finish and glass (thought to be a commonly held view) and if so, is it due to weakness of bond or is part of the glass surface detached? Further is the breakdown due to unexpectedly high interface stress concentration (possibly due to resin shrinkage) or are flaws in the fibre body or its skin responsible?

(*iii*) If the cause is found to be conditions of stress which the bond cannot reasonably be expected to carry, the critical value at which breakdown starts must be determined and physical means sought by changes to the resin and finish whereby the load pattern is improved.

Should research prove that the conditions are such that adhesion can never be fully effective, and this is not entirely impossible, this will not be a final condemnation of the material but an indication that our efforts be directed to an alternative method of protection.

We must remember that very good initial strengths have been obtained continuously under conditions where no adhesion is thought to exist, or where if it does, it is broken down before a quarter of the ultimate load has been imposed. Also where the external surface of the resin remains unbroken in such laminates no very serious deterioration occurs. So far as mechanical behaviour is concerned the only significant improvement attendant upon adhesion is an improvement in modulus in tension and bending. It is offset by a serious drop in impact strength which is alone a sufficient reason for an alternative to adhesion to be necessary in many applications.

Among the many suggestions which spring to mind, two at least are felt to offer promise of profitable investigation:

(*i*) To develop the finish into a self-sufficient surface coating capable of protecting the fibres, unaided by the resin.

(*ii*) To examine the construction and stress conditions in the glass fibre to see if there is any link between its increased tensile strength and its apparent heightened sensitivity to external attack. It may then be possible to reach some compromise between strength and chemical resistance.

As this problem emerges from the joint relationship of fibre and resin and therefore involves the resin manufacturer, glass manufacturer and moulder, it is by no means clear which, if any, of these three is best suited to undertake the necessary investigation. Indeed the work needed is so fundamental in its nature that, in all probability, the solution would come most quickly from an independent organisation.

That the problem urgently needs such investigation will undoubtedly find general agreement and the hope is

expressed that the Ministry, who have already given so much help on similar problems, may be able to include it in their programme for one of the research laboratories enjoying their financial assistance.

5. Fatigue and Creep

Fatigue and creep are such important aspects of dynamic and static behaviour that, among the welter of data accumulated around reinforced plastics materials, it is astonishing to find little or nothing published about either property.

In search for information the experiences of various people have been found to be extremely conflicting.

Ad hoc tests devised for particular structures have in general been satisfactory. As many of these structures have not been highly stressed it is difficult to say how searching these tests have been or to assess the real value of such results. As an interesting side-light, in tests where it has been necessary to transmit loads from metal to plastics, it would seem to have been a common experience to find premature failure of the joint where mechanical means and not adhesion had been used.

Where specially prepared test specimens have been tested as materials, the results do not seem to have been uniformly satisfactory. As we are only now reaching a point where laminate consistency can be produced for static tests it is very early to say how significant are the present findings. The importance of dynamic tests cannot be over-emphasised since, if any inherent weakness in fibre-reinforced material does exist, this type of examination is most likely to reveal it. In the author's opinion the progress of fatigue testing, instead of indicating new problems, can be expected to throw greater emphasis on existing ones such as the relationship which is necessary between fibre and resin. Our need for fresh fundamental knowledge about this has already been discussed.

Even if initial results are a disappointment there is no need to be discouraged. Exposing an old problem from an entirely new aspect may well give it the perspective needed to set us upon the right path of development, and thus save us many months of unprofitable investigation which could otherwise occur.

The examination of static loading (creep) behaviour is expected to follow a very similar path. As in the case of tensile and other tests initial disappointments and contradictions will be found. This can only be overcome by applying to the new tests the lessons we have already learned about producing uniformity and stability in laminates. The first necessity is to achieve consistency of results. Until this is done we can never be certain that the story told by the test results is the true story of the material.

The outcome of these tests must be conjecture but there are strong indications that, as with fatigue, old problems rather than new will be emphasised. Once again the relationship between fibre and resin is bound to play a vital part and, since the temperature behaviour of the material is progressive and follows a smooth curve, it is reasonable to expect that knowledge of what happens at moderate temperatures will be relevant to behaviour under ambient conditions.

6. Temperature Resistance

As resin manufacturers one of the most frequent questions we are asked is "What temperature will the resin withstand?" This is a most difficult question since it is capable of a number of answers. Although varying in an individual resin by about 150°C., each is equally true in the right context. The result therefore is that, whenever a short answer is given, it can either be misleading and create false hope or do serious injustice to the reputation of the particular resin. It is therefore necessary to preface this section by a short and somewhat elementary description of the way in which a laminate reacts to temperature.

Fundamentally it is true that the resin is alone in its influence on behaviour. The asbestos or glass fibres should remain unaffected at temperatures which cause disintegration of the resin but this is only the beginning of the story.

A distinction must first be made between two very different physical conditions of heat. These may be summarised colloquially but expressively as "singeing or soaking" at temperature, *i.e.* where a high temperature exists for a short time or where a moderate temperature has to be resisted over a period.

In the first case all fibre-reinforced materials behave exceptionally well and frequently show great practical advantages over metal. The low thermal conductivity and specific heat of laminates causes comparatively slow penetration and therefore confines the effect of heat to the surface. The type and chemical make-up of the resin plays very little part in this behaviour and temperatures in excess of 1,000°C. cause no difficulty in certain applications. Where the period over which the temperature to be withstood is sufficient to allow the whole moulding to reach that temperature, the behaviour of the resin at once becomes significant.

It will be recalled that the resin does not play an equal part in resisting all types of load which can be imposed upon a structure. Thus, in tension, the fibres play a prominent and immediate role in accommodating the load; whereas, in bending, the load is largely accepted by the resin and then carried uniformly to the fibres. In tension, therefore, resins can be worked at temperatures which cause appreciable softening without greatly influencing the strength of the laminate. In bending, or in any type of load where failure can be caused by induced buckling *e.g.* compression, the load which can be accommodated will be directly related to the degree of softening which has taken place in the resin at that temperature. Under these conditions, resins which progressively soften over a temperature range will restrict the use of laminates to temperatures noticeably below those at which tension structures can be worked.

Silicone resins offer the best all round thermal behaviour, but in their present state of development both cost and processing severely limit possible use. Development is continuing actively, both to remove

these limitations in the resin itself and to make use of silicones to modify, and thus improve, the thermal stability of other types of resin.

The phenolic resins come next in interest after the silicones. Although chemical deterioration sets in at about 200°C. recent types of phenolic laminating resins can be worked for useful periods at considerably higher temperatures. Some show as much as 70-75 per cent. strength retention in laminates at 250°C. continuously for 15-30 minutes. Unlike silicones their use is not limited by extremely high price, although processing calls for an application of pressure (25-50 p.s.i.) together with carefully controlled pre-cure and some breathing during the actual moulding operations.

The epoxide resins are capable of withstanding temperatures similar to those applicable to phenolics but, whereas the phenolics show little softening before actual decomposition sets in, the epoxides are more like polyesters in their behaviour. After initial good resistance to 100°C. an increase in flexibility can then be detected. This increases progressively with temperature. Among the earlier epoxide resins the best temperature resistance could only be achieved with resins which were hot set at the comparatively high (for plastics materials) moulding temperatures of 180-200°C. Cold catalysed resins showed little improvement over polyesters and were characterised by progressive softening once very modest temperatures have been passed. Developments in the past two years have led to considerable improvement in this connection.

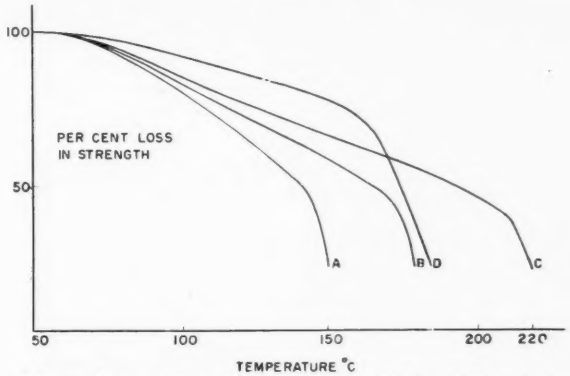
The comparatively low softening point of polyester resins has been appreciated for a long time, but the simplicity of handling these resins, together with their moderate cost (being very little dearer than phenolic resins) and valuable secondary electrical properties, made it highly prudent to spare no effort in attaining all possible improvement in temperature resistance.

To this end, the Ministry have sponsored fundamental research into both the physics and chemistry of the resin chain, various monomers and the resulting cross linkage which occurs during polymerisation. When complete this work should be of very great value, not only in the development of the highest possible temperature resistance, but with suitable extension may greatly help research going on into creep and fatigue..

As indicated, the polyester resin chemist is faced with initial loss in stiffness early in the temperature gradient, as well as the moderate ultimate temperatures at which structures can be used. Some of the new monomers already used in the U.S.A. and now becoming available over here have increased the maximum temperature (for tension applications) to above 200°C. but have not greatly helped in reducing the gap between that temperature and the initial softening point.

A further problem has been that, (with very few exceptions only), all resins behave very much alike in the lower temperature range whatever their ultimate resistance may be.

TABLE V



Effect of heat on the stiffness of Polyester/Glass cloth laminates.

Table V illustrates this point. It will be seen that some softening is present in the first three resins at between 60-70°C. Thereafter there is a similar slow and steady decline until a point is reached in the behaviour of each at which the loss is rapidly accelerated and, within a few degrees, stiffness has fallen so far as to be of no further use.

The temperature at which this accelerated loss begins is frequently referred to as the heat distortion point. This is thought to be a very misleading term since, in the case of very many resins, it overlooks the fact that the laminate has probably lost 40-50 per cent. of its initial stiffness by the time this temperature has been reached.

Because laminates in tension are not so sensitive to temperature it is customary to make all such tests in bending. Two systems are commonly used, the standard three point loading of a beam or, alternatively, to test the behaviour of the laminates as a loaded cantilever. For all but the most exacting work the second is preferred. Very simple apparatus will give consistent results and is free from the delicate refinements necessary if friction, and therefore tension, are to be eliminated from a beam loaded at three points. One other precaution is advisable, the standard load should not be too light but should cause a distinct initial deflection. Laminates tested under very light loads give results which are superficially better at the lower temperatures. These are misleading since they do not reproduce the severity of conditions likely to be encountered in an efficiently loaded structure.

The fourth resin shown in Table V behaves differently from the others. Although its ultimate resistance is very similar to the second resin, its stiffness retention at lower temperatures is very much bettter. Research is much concerned with the production of resins having this type of behaviour but retaining all the desirable handling and positive curing properties of existing resins.

It is felt that resins having temperature resistances very little better than the best of current resins, but which are substantially stable up to that temperature, will prove extremely valuable to the aircraft, as well as

other, industries and will continue to be complementary to very special resins of higher resistance now being developed but which are likely to be more costly.

This subject of temperature behaviour is very large and is sufficiently important to require a paper to itself. It is possible to show that after hot cure or post stoving, resins have better all round heat behaviour; but it is hoped that enough has been said to underline the importance of this topic to the further use of reinforced plastics, and to show that, by careful and intelligent development, the improvement necessary to keep pace with the increased speed of aircraft is largely possible. There is no ground whatever for the belief that conditions will become so severe that the use of the material will be finally eliminated.

7. Conclusion

The paper ends as it began by stressing that consistency and reliability of a material are the twin foundations upon which confidence can be built.

Without confidence in fibre-reinforced materials, whatever their theoretical possibilities, we can neither ask nor expect them to be used on primary structures. It is our immediate task therefore to do everything we can to create this confidence.

Within the four topics chosen for treatment in this paper will be found firstly the more important gaps in our knowledge, and secondly an indication of the properties which in present materials need to be improved. By concentrating our individual efforts within a framework such as this, many of the doubts hampering the general acceptance of the materials can be removed effectively and quickly.

The elements earth, water and air have in succession contributed to the advance of structures and materials. The field today is with the air. Hitherto in this medium our enterprise has rightly been curbed by our responsibility for the lives of the people necessary to flight. With the advent of rockets this restriction is removed and our thirst for innovation and improvement can be satisfied more immediately.

It is therefore logical to expect that new materials such as reinforced plastics will first be found as primary structures in robot vehicles. Later when their reliability in service has passed beyond doubt they will make their way into conventional machines.

The problems we face in reinforced plastics are no greater and no more serious than those faced by our predecessors when alloys of steel and aluminium were first developed. It is well to remember that, one by one, every difficulty has yielded to patience and research.

ACKNOWLEDGMENTS

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The Provision of Aerodrome Obstruction Data for Rational Code Civil Air Transport Operations

by

F. C. PETTS, D.F.C., A.F.R.Ae.S.,

(*Ministry of Transport and Civil Aviation*)

1. Introduction

The introduction of rational performance requirements governing the operation of civil transport aircraft has given rise to a need for accurate and detailed information on obstructions in the vicinity of aerodromes. This paper states the origin and nature of the requirement and describes a survey technique, a particular application of terrestrial photogrammetry, which was used to meet it.

2. The Origin of the Requirement

In the United Kingdom and in other member countries of the International Civil Aviation Organisation considerable progress has been made towards the rationalisation of performance requirements governing the operation of civil transport aircraft. For certain aircraft rational requirements for take-off and *en-route* performance were introduced three to four years ago, internationally in standards and recommended practices[1] of I.C.A.O. and domestically in the U.K. in Air Navigation Regulations[2] and Civil Airworthiness requirements[3]. The basis of these requirements was described by Hardingham in his Eighth British Commonwealth and Empire Lecture[4]. Proposals for rational landing requirements are still being examined. The requirements for take-off performance for Category A (large four-engined) aircraft are based upon the one-engine-cut case and are designed to give a statistically acceptable margin of safety during take-off and climb away with an engine cut at the most adverse point during the take-off run. An operator is required to adjust the take-off weight of an aircraft so that under the topographical and meteorological conditions prevailing the requisite performance margins are maintained. The aircraft flight manual contains data on the performance of the aircraft, over a range of weights, under different meteorological and topographical conditions. The topographical data needed by the operator are accurate and detailed information on the runway, any additional weight-bearing area (stopway) and any clear area (clearway), and on the position and height of obstructions which might affect the permitted take-off weight.

When the implications of the new performance regulations were considered it was evident that for few runways would suitable obstruction information be available without a special survey. It was also apparent that a progressive airline wishing to operate Category A aircraft might need obstruction data on foreign aerodromes before the appropriate authorities were willing, or able, to provide it. It was foreseen that under these circumstances an airline might wish to make its own surveys, rather than incur the prohibitive economic penalties of operating Category A aircraft without detailed aerodrome obstruction data. There thus arose a requirement for a survey technique which was accurate, quick, comparatively inexpensive and suitable for use by a very small party far from its home base.

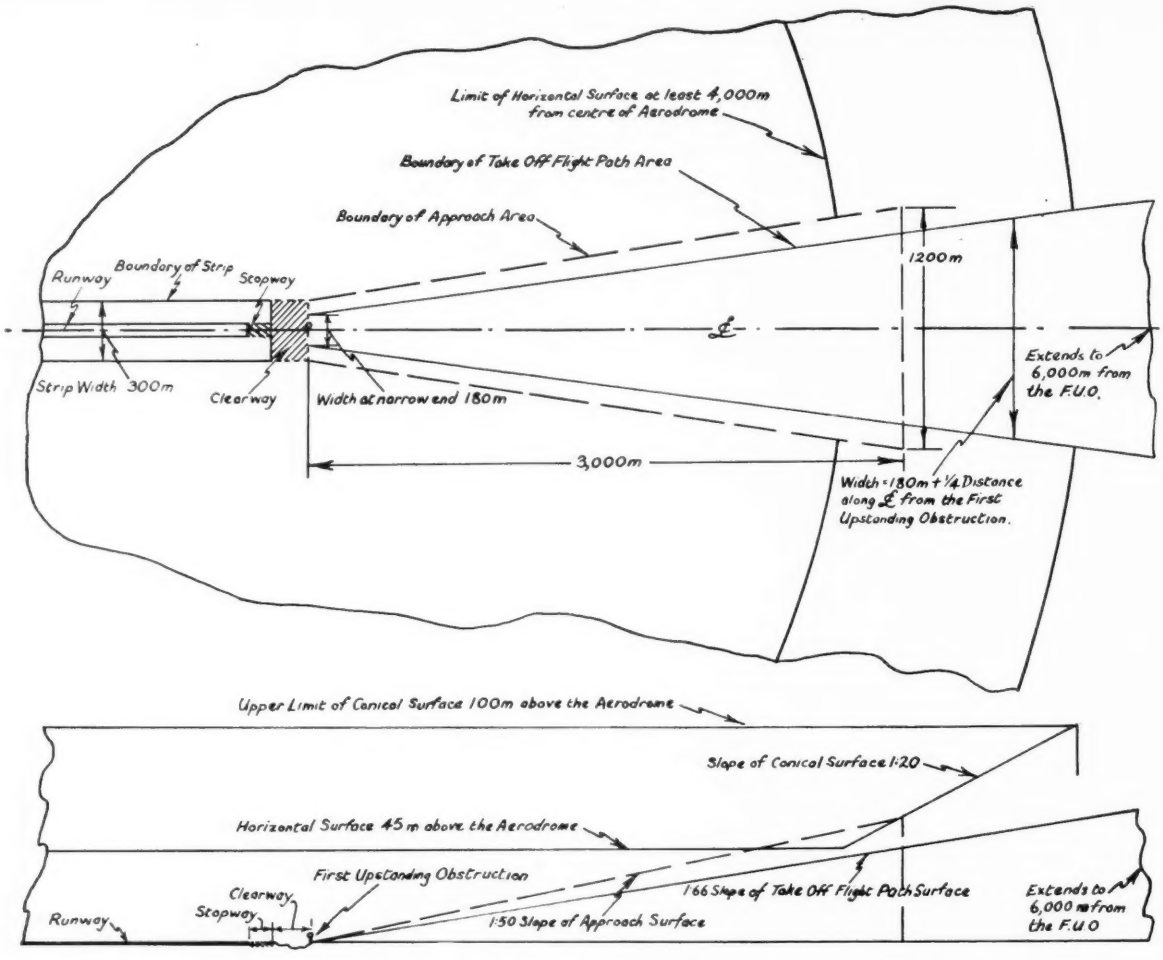
3. The Nature of the Requirement

Data on obstructions in the vicinity of aerodromes were needed even before the introduction of rational performance requirements. Some information on obstruction was, and is, necessary to meet the obstruction marking and lighting recommendations[5] of the A.G.A. (Aerodrome and Ground Aids) Division of I.C.A.O., and also for the planning of instrument procedures. The information required for these purposes is not, however, in the same category as that needed to establish compliance with performance regulations as it need not be so detailed nor so accurate and the provision or lack of it does not have so significant and direct an effect on the operating economics of civil transport aircraft.

The Fifth Session of the M.A.P. Division of I.C.A.O. considered how data on obstructions in the vicinity of aerodromes should be presented and, taking account of the needs of obstruction lighting and marking, instrument procedures and performance regulations, made recommendations[6] as to the form which aerodrome construction plans and profiles should take, and on the accuracy desirable in the survey work. The surfaces to be surveyed and the recommended tolerances are illustrated in Fig. 1.

A survey specification based upon the tolerances recommended by I.C.A.O. does not readily lend itself to interpretation by any one method. Ground position to ± 5 metres irrespective of the distance from the aerodrome, is obtained easily by air photography but not so readily by ground surveys. Heights of

Revised paper received 14th April 1955.


Limit of Horizontal Surface at least 4,000m from centre of Aerodrome
Boundary of Take Off Flight Path Area
Boundary of Approach Area
Runway
Boundary of Strip
Stopway
1200m
Strip Width 300m
Clearway
Width at narrow end 180m
3,000m
Extends to 6,000m from the F.U.O.
Width = 180m + ¼ Distance along ℄ from the First Upstanding Obstruction.
Upper Limit of Conical Surface 100m above the Aerodrome
Slope of Conical Surface 1:20
Horizontal Surface 45m above the Aerodrome
First Upstanding Obstruction
Clearway
Stopway
Runway
1·66 Slope of Take Off Flight Path Surface
1·50 Slope of Approach Surface
Extends to 6,000m from the F.U.O

Obstructions to be recorded.		Ground Position to	Height to
1. In vicinity of runway		± 5m	± 5m
2. In the Take Off Flight Path Area if infringing the 1:66 slope & if not in the shadow of another obstruction.	Distance out from F.U.O.		
	0 – 1,500m	± 5m	± ·5m
	1500 – 3,000m	± 5m	± 1m
	3,000 – 4,500m	± 5m	± 1·5m
	4,500 – 6,000m	± 5m	± 2m
3. In the Approach Area if infringing the 1:50 Slope			
4. Infringing the Horizontal Surface	Distance from the Aerodrome Centre		
	0 – 1,500m	± 5m	± 1m
	1,500 – 2,000m	± 5m	± 1·5m
	2,000 – 2,500m	± 5m	± 2m
	2,500 – 3,000m	± 5m	± 2·5m
	3,000 – 3,500m	± 5m	± 3m
	3,500 – 4,000m	± 5m	± 3·5m
	4,000 – 4,500m	± 5m	± 4m
5. Infringing the Conical Surface		± 5m	± 5m.

FIGURE 1. Obstruction survey requirements to meet I.C.A.O. recommendations.

obstructions near the aerodrome to $\pm 0{\cdot}5$ metres present no difficulty with ground techniques but, with aerial survey, they entail photography from a low altitude and a consequent increase in the numbers of runs and photographs and the overall cost.

When considering how best surveys could be made on behalf of an airline wishing to operate Category A aircraft, the following conditions were seen as governing the choice of method.

(*i*) The survey need cover only the take-off areas and the take-off flight path areas.
(*ii*) The data obtained must be complete and possess accuracy of the order called for by I.C.A.O., although some relaxations might be possible to meet individual cases.
(*iii*) Time spent on the field work must be short and the size of the party kept to a minimum.
(*iv*) The time between starting the survey and producing the plans and profiles must be kept down, as must also the overall cost in man-hours.
(*v*) The weight of equipment to be carried must not be excessive.
(*vi*) To avoid difficulties with authorities not directly concerned with aerodromes all the field work must be done from within aerodrome boundaries.
(*vii*) The method should be self-checking, particularly in respect of measurements and observations made in the field, as there could be no going back for a second look.
(*viii*) A permanent photographic record was desirable.
(*ix*) The method should lend itself to quick and inexpensive checks to keep the obstruction data up-to-date.

4. Steps Taken to Meet the Requirement

Attention was directed to the possibilities of terrestrial photogrammetry using certain available equipment. After some initial experiments, and a brief practice run in the United Kingdom, a technique was evolved which was used successfully at a number of overseas aerodromes, beginning in the Spring of 1951.

5. The Phototheodolite Method

5.1. PHOTOGRAMMETRIC INTERSECTION

Photogrammetric intersection, the basis of terrestrial photogrammetry, is accomplished by means of a phototheodolite which is a combination of calibrated camera and theodolite. The theodolite is used to orient the camera in azimuth and elevation.

The area to be surveyed is photographed from either end (I, II) of a measured baseline of suitable length. For each photograph the outer orientation of the camera is set and read with reference to the base. The plate co-ordinates x', z' (lateral and vertical displacement on the left hand plate) and x'', z'' (lateral and vertical displacement on the right hand plate) for any object in the field of overlap of the two photographs may be measured on a suitable comparator. The outer co-ordinates X, Y, Z (lateral, longitudinal and vertical displacements respectively) can then be calculated from the measured plate co-ordinates and the inner and outer orientation data. Formulae for parallel normal orientation and other arrangements are given by Zeller[7].

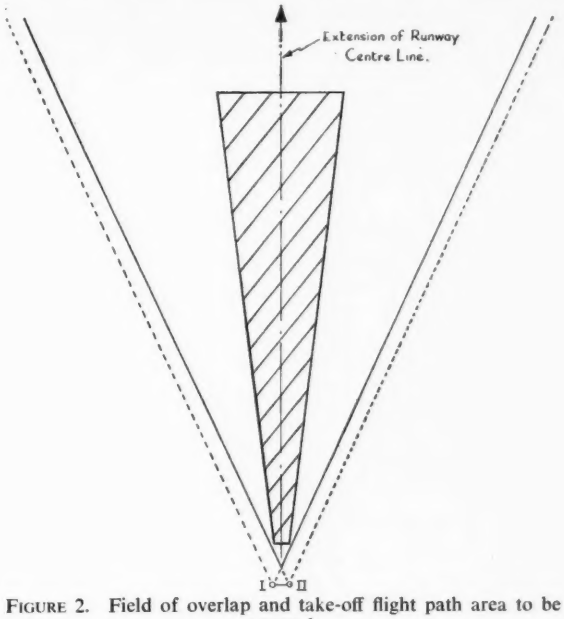


FIGURE 2. Field of overlap and take-off flight path area to be covered.

Alternatively, an automatic plotter may be used and the calculations avoided. If a comparator is to be used it is especially advantageous to take the photographs from I, II with parallel axes, as corresponding points on the plates can then be viewed as a three-dimensional image. Precise measurement is thus facilitated and mal-identification, which can occur with ordinary theodolite intersection and also with non-parallel photogrammetric intersection, is less likely to occur.

5.2. LENGTH OF BASE

The length of base required depends upon the maximum range, $Y_{max.}$, to be covered and the accuracy required in the results. The length actually used will be influenced by topographical conditions. Von Gruber[8] suggests that as a general rule the base length, b, should not be less than $1/20\ Y_{max.}$ to achieve an accuracy of 1:1,000 in $Y_{max.}$ In an extreme case the most distant objects to be fixed and heighted are at the extremity of the take-off flight path area 6,000 metres from the aerodrome boundary and bases 300 metres or more in length are needed to maintain the ratio of $b = 1/20\ Y_{max.}$ At most aerodromes local topography precludes the use of bases of this length and in practice bases 200 to 230 metres long are used. These lengths are acceptable because most of the obstructions infringing a particular take-off flight path slope will be much less than 6,000 metres from the aerodrome, and, in exceptional cases, greater errors in range than 1:1,000 can be accepted.

5.3. THE FIELD OF OVERLAP

The angular field of the Zeiss TAN phototheodolite is 42 grads. The field of overlap from a 200 metre base as applied to a take-off flight path area is shown in Fig. 2. It will be appreciated that a take-off flight path area is a convenient shape which can be covered by the overlap of one pair of photographs from a suitably sited base.

5.4. CHECK POINTS

The orientation and levelling of the phototheodolite can be checked if the true co-ordinates of a number of objects or "check points" in the field of overlap are known or can be determined. In many aerodrome obstruction surveys the positions and heights of check points are not available from existing data and it is necessary to establish them by triangulation from the photogrammetric bases. If a theodolite giving a sufficiently high order of accuracy is used, co-ordinates obtained by this triangulation can be accepted as "true" values and those obtained photogrammetrically compared with them.

5.5. ACCURACY OF THE RESULTS

Errors from three sources are possible in phototheodolite surveys—errors of the inner orientation of

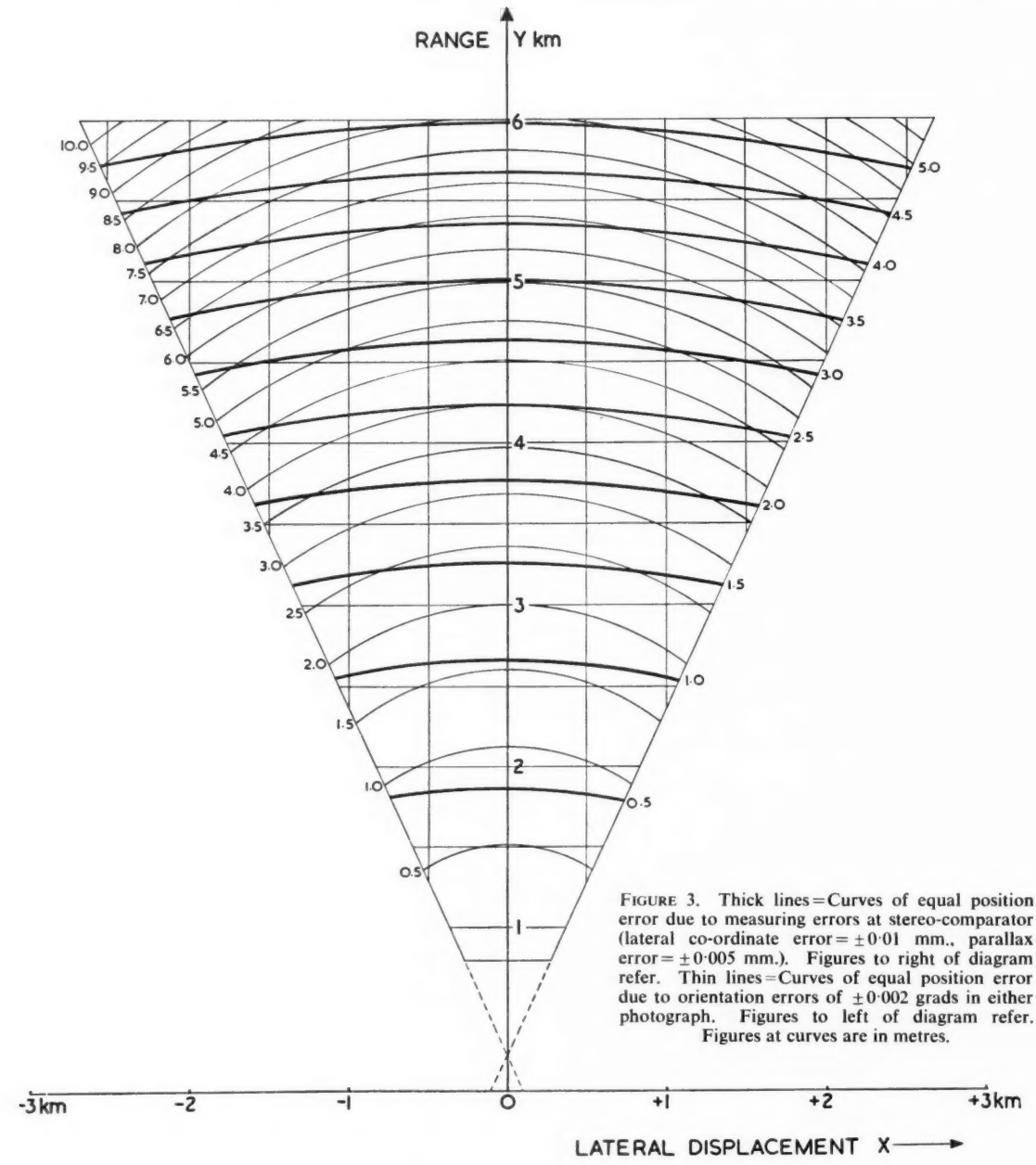


FIGURE 3. Thick lines = Curves of equal position error due to measuring errors at stereo-comparator (lateral co-ordinate error = ±0·01 mm., parallax error = ±0·005 mm.). Figures to right of diagram refer. Thin lines = Curves of equal position error due to orientation errors of ±0·002 grads in either photograph. Figures to left of diagram refer. Figures at curves are in metres.

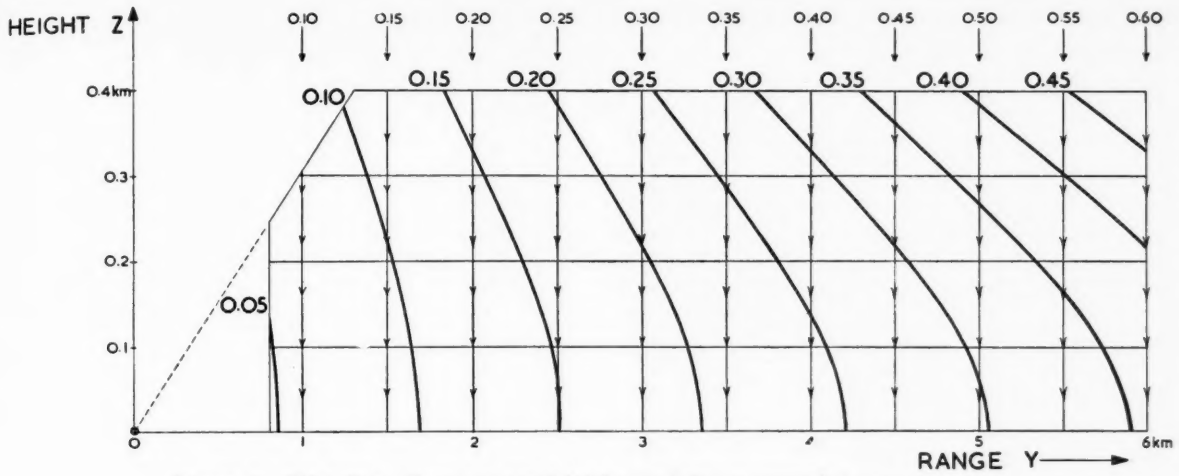


FIGURE 4. Thick lines = Curves of equal height error due to measuring errors at stereo-comparator (vertical co-ordinate error = 0·01 mm., parallax error = 0·005 mm.). Arrowed lines = Curves of equal height error due to calibration error of ±0·02 mm. Curves coincide with grid lines. Y = const. indicated by arrow. Figures at curves are in metres.

the camera (length of principal distance, position of principal point), errors of the outer orientation of the camera (base length, angle of azimuth, angle of elevation, angle of swing) and errors in the plate measuring. The effect of these various errors has been dealt with elsewhere[9] and here it is sufficient to point out that if equal care is taken in measuring all the foregoing quantities, the accuracy to which the ground position is established will be influenced primarily by outer orientation errors in azimuth, and by errors in the measuring of the plates. The determination of moderate heights (up to 200 metres above camera level) is mainly affected by any calibration error in the principal point, and plate measuring errors.

In Fig. 3 curves are plotted showing the mean position errors M which are to be expected for well-defined points in a normal orientation overlap using a base of 200 metres. At a range of 6 km. $M = \pm 5$m. This means that the rather tight I.C.A.O. tolerance of ±5m. for ground position can, for well-defined points, be met at that range from a 200 metre base if the outer orientation errors have been eliminated by the use of check points. For comparison, curves M = constant are plotted in the same figure to show the effect of outer orientation errors.

In Fig. 4 are plotted curves of constant height error due to plate measuring errors and errors in the calibration of the principal point. If any calibration error is detected and a suitable correction introduced, for heights up to 200 metres above camera level the height errors are only of the order of 0·4 metres at a range of 6 kms. It follows that the height error at 6 kms. is well within the ±2m. specified by I.C.A.O. for that range. It will be noticed from Figs. 3 and 4 that errors in the ground position vary approximately as the square of the range Y, while, for moderate heights, height errors are directly proportioned to the range.

6. The Application of the Phototheodolite Method

6.1. THE EQUIPMENT

The equipment (Fig. 5) which has been carried weighs, with containers, 100 to 120 kilos. It includes a complete dark room outfit, an ordinary camera for taking incidental photographs and such detailed items as chalk and paint for marking runways. Used at home for the evaluation of the photographs and preparation of the survey results were a stereo-comparator, an electric calculator and normal drawing office and photographic dark room equipment.

Two items deserve special mention.

The Zeiss TAN phototheodolite (Fig. 6) has a focal length of 192 mm., a fixed aperture of f:25, and takes plates 13 × 18 cm. Originally exposures were made by the manual removal and replacement of a cap over the lens, but to gain more control over exposure times and to reduce the dangers of disturbing the instrument a Compur shutter with cable release was fitted. To help eliminate trouble with glare a polar screen was fitted to the shutter mounting.

The phototheodolite is fitted with sensitive levelling bubbles and is mounted on a normal Zeiss tribrach. The theodolite telescope on top of the camera has vertical and horizontal circles graduated in the centesimal system. This telescope is used for setting the camera axis in relation to the base line, but it is not satisfactory for the establishment of control through the medium of check points.

For the fixing of check points use was made of a Zeiss II theodolite. This is a double faced instrument. It has internal circles reading to 0·0001 grads and is suitable for second order triangulation. The particular instrument graduated in the centesimal system was chosen as the phototheodolite circles were in grads and all work was carried out in metric units.

FIGURE 6. Zeiss TAN Phototheodolite.

FIGURE 5. The field equipment.

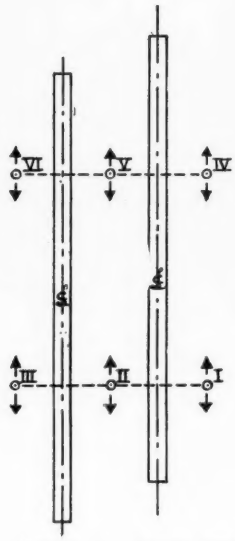


FIGURE 8. Layout used for two parallel runways.

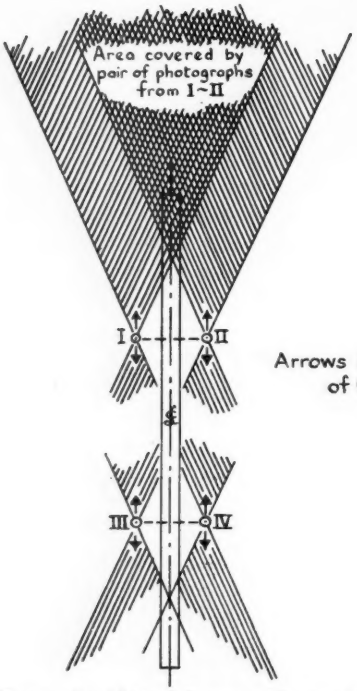


FIGURE 7. Normal layout with two baselines approximately symmetrical about runway centre line.

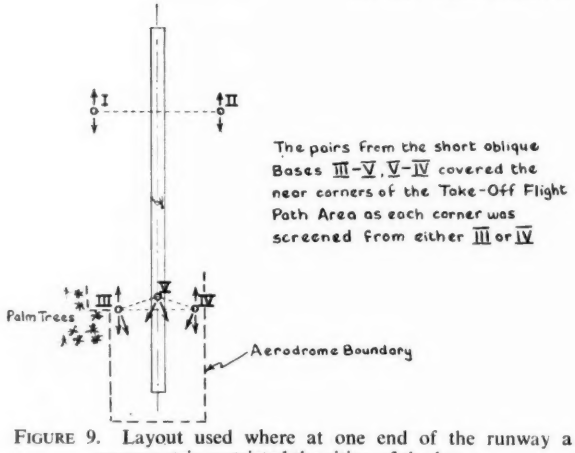

I
II
III
IV
V
Palm Trees
Aerodrome Boundary
The pairs from the short oblique Bases III-V, V-IV covered the near corners of the Take-Off Flight Path Area as each corner was screened from either III or IV

FIGURE 9. Layout used where at one end of the runway a narrow strip restricted the siting of the bases.

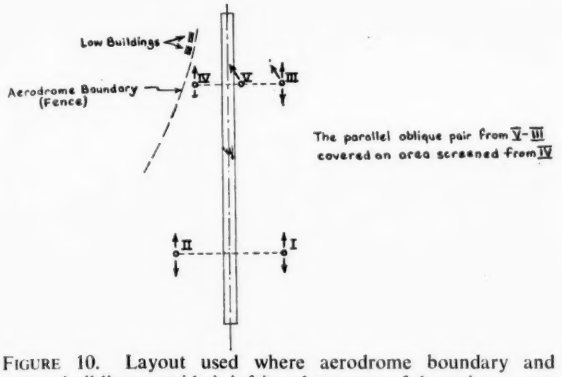


FIGURE 10. Layout used where aerodrome boundary and buildings outside it infringed a corner of the strip.

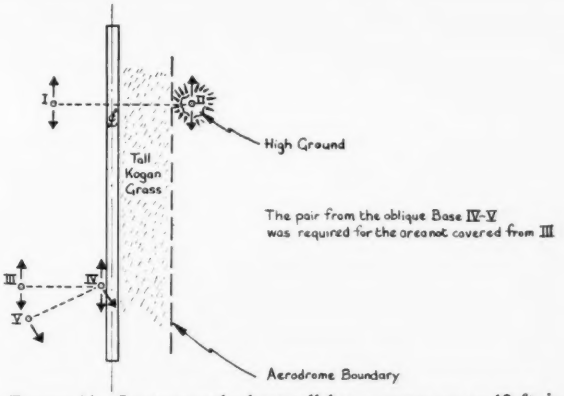

High Ground
Tall Kogan Grass
The pair from the oblique Base IV-V was required for the area not covered from III
Aerodrome Boundary

FIGURE 11. Layout used where tall kogan grass up to 12 ft. in height covered one side of the strip.

6.2. FIELD WORK

The drills followed in the field and in the evaluation of the results were designed to be self-checking. In the field the normal and simplest layout consisted of two base lines of suitable length set across the runway at right angles to the centreline at appropriate distances from the runway ends (Fig. 7). Each take-off flight path area was covered by photographs from the two bases. The photographs from the forward base provided most of the information on the near obstructions; those from the rear base gave duplicate cover of the same area and sometimes revealed significant objects which were screened from the forward base.

Each photograph was duplicated and on the later surveys it was usual to take a pair with rapid orthochromatic plates and the duplicate pair with fine grain panchromatic plates.

It was essential that the success of a survey should not depend upon the reliability of existing information. The practice was to consult, but not to rely on, any available maps and drawings. The centrelines painted on runways were generally found to be inaccurately positioned and it was necessary to start each survey by establishing a true centreline to which the obstructions could be related. On runways which were not straight, or were not of uniform width, the best possible mean centreline was used. Heights were presented in metres and feet above the level of the runway end, or the level of the ground at the first upstanding obstruction, and also above mean sea level. Only for reduction of heights to mean sea level was it necessary to use an existing datum.

It was not always possible to use the simple layout shown in Fig. 7; others which have been used are illustrated in Figs. 8 to 12. Most of these more complicated arrangements were chosen because there were no simpler ways of getting the necessary photographic cover of the areas to be surveyed. In one case (Fig. 10) a parallel oblique pair of photographs from part of a main base line was used, owing to reluctance to set up a subsidiary base line off the beaten track in cobra country. As it happened the only snakes encountered were little ones, although on another part of the aerodrome a peon was bitten by a cobra.

Of the base line arrangements illustrated in Figs. 8 to 12 the only one worthwhile for its own sake is that shown in Fig. 12 with three base points in a row, the middle one being on the runway centreline. This set-up is a good one but it can be used only where it is possible to have undisturbed use of the runway at the appropriate time. Photographs from the three points, if the setting up is sufficiently accurate, can be used as three pairs, *i.e.* I-II, I-III and III-II. This makes easier the identification of difficult targets and also permits the long base to be set nearer the runway end as what would otherwise be dead ground is covered from the shorter bases.

6.3 EVALUATION OF THE DATA

For the series of surveys on which this paper is based a stereo-comparator was used for the evaluation of the photographic data. It is realised that an automatic plotter could have lightened the labour but such an instrument was not readily available. The procedure described here is that followed with the stereo-comparator.

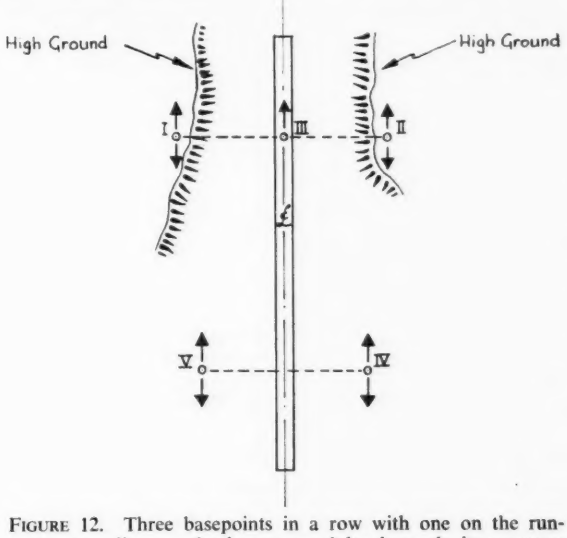


FIGURE 12. Three basepoints in a row with one on the runway centre line, used where ground levels made it necessary to site a long base close to the runway end.

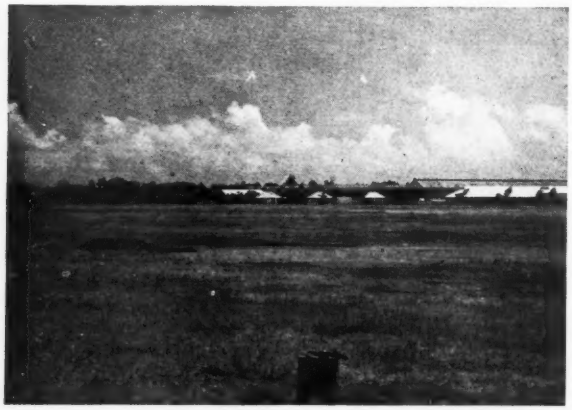


FIGURE 13(*a*).

FIGURE 13(*b*).

Extracts from a stereopair of a take-off flight path area.

First the several bases are related to each other and to the true centreline.

Next the "true" co-ordinates of the check points are compared with those obtained photogrammetrically and any corrections to plate readings calculated. The plates are systematically searched and readings taken for all objects which appear relevant. Co-ordinates are calculated, corrections applied and the points plotted. This procedure is repeated as necessary and plots from the several bases are combined.

The results for each aerodrome are presented finally as fair drawings of one or more obstruction plans and their associated profiles, schedules of co-ordinates, prints off relevant photographs and a covering description of the aerodrome.

Figs. 13(*a*) and (*b*) are extracts from a pair of survey photographs and Fig. 14 shows an extract from the obstruction plan prepared from them. The photographs were a normal parallel pair taken from points III-IV in Fig. 9. The area shown, with its large number of close-in obstructions, is hardly typical of the take-off flight path areas surveyed, but the illustrations do indicate the relationship between the photographic data and the finished product. Where there was rising ground in a take-off flight path area there was a greater number of objects infringing the take-off flight path surface.

7. The Work which has been done and Possible Future Developments

Surveys with this technique were completed on twelve runways at eight aerodromes, most of them in the tropics. The work was often carried out under adverse conditions. There were interruptions from dust storms and from tropical thunderstorms and, on one occasion with temperatures of 120°F. in the shade, plates were spoilt by the heat. Dark rooms used included, at one extreme, air-conditioned premises with temperature controlled tanks and, at the other, a small room with cold water at 95°F. and no ice. In several places developing and printing were carried out in hotel bathrooms.

No attempt was made to work from bases outside aerodromes nor to extend the cover to include areas outside those of interest in the application of performance requirements.

No provision was made for resurveying any aerodrome but, if there had been a requirement to do so to keep information up-to-date, base points could have been permanently marked. To resurvey, it would be sufficient to set up and re-photograph from the permanent points: no other field work would be necessary. At home the new plates would be compared with the old and evaluated only in respect of any new obstructions.

For the first surveys only fine grain orthochromatic plates were used. Later practice was to take a pair of photographs with orthoplates and to duplicate them with fine grain panchromatic plates. Subsequent trials with infra-red plates gave satisfactory results and in future the choice would be panchromatic duplicated by infra-red.

As already mentioned, all plates were measured on a stereo-comparator. Later some of them were tried on an automatic plotter and it was apparent that the use of such a machine would result in a considerable saving of time and effort.

8. The Cost of Surveys by the Phototheodolite Method

The cost of obstruction surveys by this method can be considered under the following headings:—

EQUIPMENT

The field equipment illustrated in Fig. 5 is valued at approximateley £1,100, the stereo-comparator at £300 and the electric calculator at £300. Expendable photographic items cost between £5 and £10 an aerodrome.

TRANSPORT

The transport charges are for passages, normally air passages, for two people plus 120 kilos of equipment, and for the use of ground transport. It is essential to have the full use of a car during the field work.

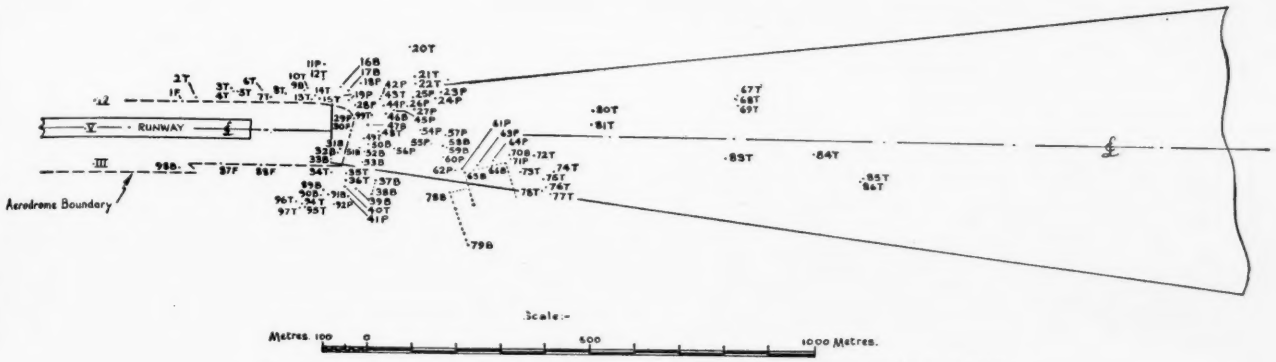


FIGURE 14. Extract from obstruction plan of area illustrated in Figs. 13(*a*) and 13(*b*).

SALARIES AND ALLOWANCES

The practice has been for two men to carry out the field work. For the evaluation and computation they were joined by a third who specialised in the use of the comparator and the drawing.

The addition of a third member to the team in the field would, under certain circumstances, shorten the time taken for that part of the work but may be regarded as unnecessary luxury. It is not practicable for one experienced man to do the field work with only unskilled assistance. At a one-runway aerodrome with no undue complications two men can complete the field work, including developing and printing of photographs, in one week. The time taken at home depends on what is required in the final documents, on the layouts used in the field and on the number and nature of obstructions which are being surveyed. It has been possible to produce prints off a squared paper plot within a week of starting on the evaluation of a take-off flight path area. The cost, including production of prints off the plot and off the photographs has been 11 to 15 man days. Such a first plot is regarded as sufficient for an initial appreciation of an aerodrome. All the evaluation work is subject to recheck and this, with the production of fair drawings and schedules of co-ordinates, takes five to ten days a runway.

9. Conclusion

It is claimed for the phototheodolite technique used in the series of surveys described that, in the special circumstances, it was superior to other methods. There is little doubt that terrestrial photogrammetry could with advantage be used for other obstruction surveys made under less restrictive conditions, and there are obvious possibilities in a combined use of aerial and terrestrial photogrammetry.

In conclusion, it is perhaps appropriate to quote a passage written by Von Gruber 25 years ago: "The astonishing advantage of terrestrial photogrammetry above all other methods of exploratory survey is incontestable. For technical surveys Domansky's saying unfortunately still holds good: 'The greater accuracy and speed of stereo-photogrammetry is willingly noticed but unwillingly financed.' In the sphere of mapping aerial photogrammetry is in general superior to ground photogrammetry."

ACKNOWLEDGMENTS

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The views expressed are those of the author and are not necessarily those of the Ministry of Transport and Civil Aviation.

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APPENDIX

Stereo-comparators and Stereoplotting Machines

Fig. 15 illustrates a Zeiss stereocomparator and Fig. 16, for comparison, the Thompson-Watts stereoplotting machine, a modern British instrument.

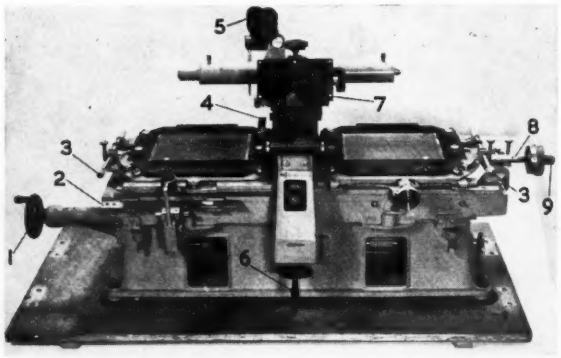

FIGURE 15 (*above*). Zeiss Stereo-comparator.

1. Wheel for x' movement
2. x' scale
3. Adjustment screw for swing
4. z' scale
5. Reading telescope for z' scale
6. Wheel for z' movement
7. Stereo-microscope
8. Scale for parallax p
9. Parallax drum

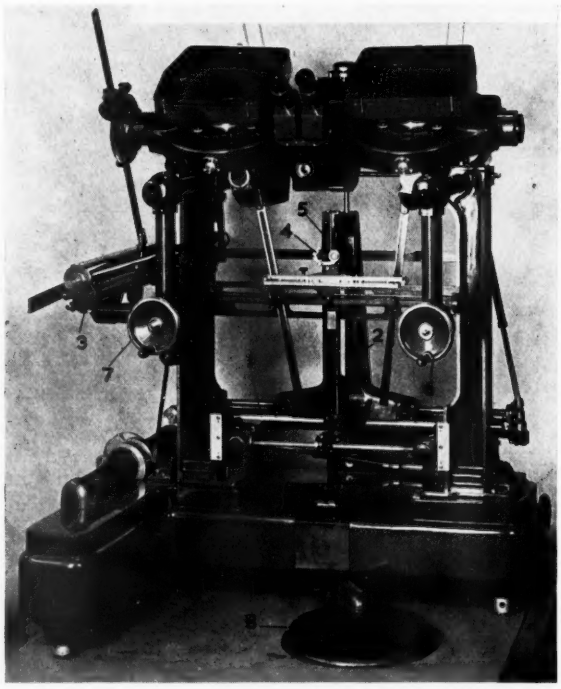

FIGURE 16 (*right*). Thompson-Watts Stereo-Plotter.

1. X slide
2. X carriage
3. Y slide
4. Z nut
5. Z slide and screw
6. Wheel controlling X carriage
7. Wheel controlling Y carriage
8. Foot-wheel controlling Z nut

On the comparator the two plates of a stereopair, fitted and aligned in their respective left-hand and right-hand positions, are viewed stereoscopically through the binocular microscope. For each point of interest readings (to 0·01 or 0·005 mm.) are taken on three scales—x', the lateral displacement from the principal point on the left-hand plate, p, the parallax, which is the difference between the lateral displacements on the two plates, and z', the displacement on the left-hand plate above or below the principal point. From these plate measurements, and the base length and camera focal length, rectangular co-ordinates related to the left-hand base point are calculated.

The Thompson-Watts stereoplotting machine possesses features not found in earlier, more widely-known continental models. It has been fully described elsewhere.* In principle the measurements made on a stereoplotter are the same as those made on a comparator but conversion of the data to rectangular co-ordinates is done by the machine and tedious calculations are eliminated. The X and Y (plan) co-ordinates are transferred to mutually perpendicular movements of a pencil on a drawing-table, lying in the case of the Thompson-Watts machine, to the right of the instrument but not shown in Fig. 16.

**The Photogrammetric Record*, Vol. 1, No. 3, April 1954. The Photogrammetric Society.

TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within two months of being received.*

Reciprocation of Triply-Partitioned Matrices

by

Professor W. J. DUNCAN, C.B.E., D.Sc., F.R.S., F.R.Ae.S.

(Department of Aeronautics and Fluid Mechanics in the University of Glasgow)

A METHOD is given for finding the reciprocal of a matrix which is triply partitioned horizontally and vertically in such a manner that the sub-matrices in the principal diagonal are square, but these matrices need not be of the same order. A preliminary rearrangement of the matrix may be helpful.

1. INTRODUCTION

In theoretical work it is sometimes required to find the reciprocal of a matrix which can be so partitioned that some of the sub-matrices are of simple types, *e.g.* triangular or nul matrices, and the calculation of the reciprocal may then be facilitated by using formulae for the inversion of partitioned matrices. The same method will be often advantageous in numerical work also. In an earlier paper the reciprocation of doubly-partitioned matrices was treated in a general way and a method was given for triply-partitioned matrices subject to the restriction that the sub-matrices in the principal diagonal are square and of the same order. The method now given is applicable irrespective of the orders of the matrices in the principal diagonal, but these must still be square, which requires that the horizontal and vertical partitioning be done identically. The method is explained without proof in Section 2 while the proof is supplied in Section 3. In Section 4 the basic theory of the preliminary rearrangement of the matrix (which may be advantageous) is set out.

2. STATEMENT OF THE METHOD

The partitioned matrix to be reciprocated is

$$U=\begin{bmatrix} A & B & C \\ D & E & F \\ G & H & J \end{bmatrix} \quad . \quad . \quad (1)$$

where the capital letters represent the sub-matrices while A, E and J are square and of orders r, s and t respectively. The reciprocal is

$$U^{-1}=\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & j \end{bmatrix} \quad . \quad (2)$$

where any sub-matrix in (2) is of the same order as the corresponding sub-matrix in (1). All the unknown sub-matrices in (2) may be calculated from the following formulae:

$$a=N^{-1} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where $$N=A-LK^{-1}D-MJ^{-1}G \quad . \quad . \quad (4)$$

with $$K=E-FJ^{-1}H \quad . \quad . \quad . \quad . \quad (5)$$

$$L=B-CJ^{-1}H \quad . \quad . \quad . \quad . \quad (6)$$

and $$M=C-LK^{-1}F. \quad . \quad . \quad . \quad (7)$$

$$b=-aLK^{-1} \quad . \quad . \quad . \quad . \quad (8)$$

$$c=-aMJ^{-1} \quad . \quad . \quad . \quad . \quad (9)$$

$$e=S^{-1} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where $$S=E-QP^{-1}B-RJ^{-1}H \quad . \quad . \quad (11)$$

with $$P=A-CJ^{-1}G \quad . \quad . \quad . \quad . \quad (12)$$

$$Q=D-FJ^{-1}G \quad . \quad . \quad . \quad . \quad (13)$$

and $$R=F-QP^{-1}C. \quad . \quad . \quad . \quad . \quad (14)$$

$$d=-eQP^{-1} \quad . \quad . \quad . \quad . \quad (15)$$

$$f=-eRJ^{-1} \quad . \quad . \quad . \quad . \quad (16)$$

$$g=-J^{-1}(Ga+Hd) \quad . \quad . \quad . \quad (17)$$

$$h=-J^{-1}(Gb+He) \quad . \quad . \quad . \quad (18)$$

$$j=J^{-1}-J^{-1}(Gc+Hf). \quad . \quad . \quad (19)$$

Since matrix multiplication is, in general, non-commutative, the order must be strictly preserved in all products.

In the application of the method the partitioning will be arranged so that the sub-matrix J is easily reciprocated. It should not be overlooked that it may be advantageous to rearrange the matrix before partitioning in accordance with the following rules:

(*i*) When two rows of a matrix are interchanged the corresponding columns of the reciprocal are interchanged.

(*ii*) When two columns of a matrix are interchanged the corresponding rows of the reciprocal are interchanged.

The proofs of these rules are given in Section 4. The method will fail when J (or the auxiliary matrices K and P) is singular. Provided that U itself is not singular it must be possible to do the partitioning so that failure does not occur.

3. PROOF OF THE METHOD

Since the matrix (2) is the reciprocal of (1) we have

$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & j \end{bmatrix}\begin{bmatrix} A & B & C \\ D & E & F \\ G & H & J \end{bmatrix}=\begin{bmatrix} I_r & 0 & 0 \\ 0 & I_s & 0 \\ 0 & 0 & I_t \end{bmatrix} \quad . \quad . \quad . \quad . \quad . \quad (20)$$

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where I_n stands for the unit matrix of order n. By consideration of the first row of the product we get three equations to determine the unknown matrices a, b and c:

$$aA+bD+cG=I_r \quad . \quad . \quad . \quad (21)$$

$$aB+bE+cH=0 \quad . \quad . \quad (22)$$

$$aC+bF+cJ=0. \quad . \quad . \quad . \quad (23)$$

Now a linear equation can be solved for an unknown matrix when its coefficient is a non-singular square matrix. We assume J to be non-singular and post-multiply (23) by J^{-1}. Then we get

$$c=-(aC+bF)J^{-1} \quad . \quad . \quad . \quad (24)$$

and (22) now yields

$$bK=-aL \quad . \quad . \quad . \quad . \quad (25)$$

where K and L are defined in (5) and (6) respectively. K is a square matrix of order s and, provided it is non-singular, we may solve (25) for b thus

$$b=-aLK^{-1}. \quad . \quad . \quad . \quad . \quad (26)$$

Equation (24) now gives

$$c=-aMJ^{-1} \quad . \quad . \quad . \quad . \quad (27)$$

where M is given by (7). Finally (21) becomes on substitution

$$a(A-LK^{-1}D-MJ^{-1}G)=I_r \quad . \quad . \quad (28)$$

which yields equation (3). The three unknown matrices a, b and c are now determined.

The set of equations obtained from the second row of the product in (2) is

$$dA+eD+fG=0$$
$$dB+eE+fH=I_s$$
$$dC+eF+fJ=0.$$

The last equations can be rearranged as

$$eE+dB+fH=I_s \quad . \quad . \quad (29)$$

$$eD+dA+fG=0 \quad . \quad . \quad (30)$$

$$eF+dC+fJ=0 \quad . \quad . \quad (31)$$

and are now of exactly the same form as equations (21) . . . (23). The same method of solution can be used and the resulting equations are (10) . . . (16). Similarly, the set of equations obtained from the third row of the product in (20) can be re-arranged as

$$jJ+hF+gC=I_t \quad . \quad . \quad (32)$$

$$jH+hE+gB=0 \quad . \quad . \quad (33)$$

$$jG+hD+gA=0 \quad . \quad . \quad (34)$$

which can be solved for g, h and j as before. There is, however, a much simpler method of obtaining these. In equation (20) we may reverse the order of the matrices on the left and we then get from the third row of the product

$$Ga+Hd+Jg=0 \quad . \quad . \quad (35)$$

$$Gb+He+Jh=0 \quad . \quad . \quad (36)$$

$$Gc+Hf+Jj=I_t. \quad . \quad . \quad (37)$$

Since the matrices a, b, . . . f have already been found, the last equations can be solved at once for g, h and j (*see* equations (17) . . . (19)). Equations (32) . . . (34) may be used for checking.

4. REARRANGEMENT OF THE MATRIX TO BE RECIPROCATED

Let I_{rs} denote a " deranged unit matrix " obtained from the unit matrix I by interchange of the r^{th} and s^{th} columns. Then I_{rs} can also be obtained from I by interchange of of the r^{th} and s^{th} rows. It can easily be verified that I_{rs} has the following properties:

(*i*) $I_{rs}U$ is obtained from U by interchange of the r^{th} and s^{th} rows.

(*ii*) UI_{rs} is obtained from U by interchange of the r^{th} and s^{th} columns.

(*iii*) $$I_{rs}^{-1}=I_{rs}. \quad . \quad . \quad . \quad (38)$$

Now let $$V=I_{rs}U. \quad . \quad . \quad . \quad (39)$$

By the reversal rule in the reciprocation of a product

$$V^{-1}=U^{-1}I_{rs}^{-1}=U^{-1}I_{rs} \quad . \quad . \quad (40)$$

by equation (38). But V is obtained by interchanging the r^{th} and s^{th} rows of U while $U^{-1}I_{rs}$ is obtained by interchanging the r^{th} and s^{th} columns of U^{-1} and rule (*i*) of Section 2 is proved. Similarly if

$$W=UI_{rs} \quad . \quad . \quad . \quad . \quad (41)$$

we find that $$W^{-1}=I_{rs}U^{-1}. \quad . \quad . \quad . \quad (42)$$

From this the truth of rule (*ii*) of Section 2 follows.

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Loss Due to Leakage in Unshrouded Radial Impellers

by

Professor Dr. Ing. L. G. VALDENAZZI

(Professor of Mechanical Engineering, University of Genoa; Head, Gas Turbine Research Dept., Ansaldo Co., Genoa)

UNSHROUDED impellers of centrifugal compressors and centripetal turbines manifest an increase of the flow losses in comparison with the shrouded ones. Assuming that the controlling factor in such increase of loss is the leakage through the gap between wheel and casing, the author develops a simple theory leading to a formula for the volumetric efficiency. Only one experimental quantity is required for applying the formula; and tentative values, based on some experimental evidence, are presented.

Difficulties in manufacture require most radial wheels of high speed centrifugal compressors and centripetal turbines to be unshrouded. Compared with shrouded

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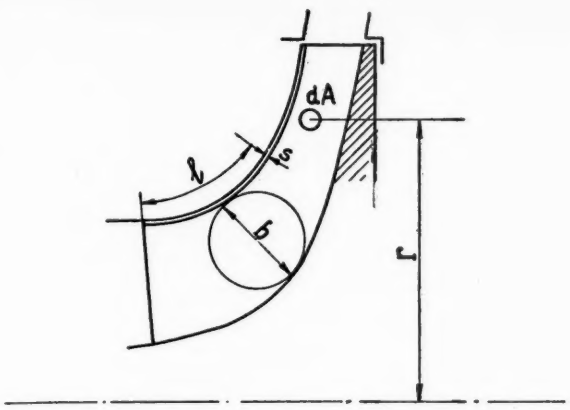

FIGURE 1.

wheels, the unshrouded ones manifest an increase of the flow loss, especially in the case of small wheels and large clearances.

The mechanism of such loss increase is fairly complicated, but it is likely to be associated with the following peculiarities of the flow within unshrouded wheels:

(*a*) One of the walls of a wheel channel is no longer stationary with regard to the relative flow, and the friction path of a fluid particle moving near the casing is usually longer than that of a particle moving along one of the other walls;

(*b*) Because of the pressure difference between both sides of a blade, some fluid leaks out of the high pressure side to the low pressure side;

(*c*) Considering that the temperature of the fluid leaked is higher than the temperature of the main flow near the low pressure side of the blade, the compression efficiency is somewhat reduced by the ensuing heating;

(*d*) The motion in the boundary layer adhering to the casing is influenced by the scraping action of the blades and by the drag of the (absolute) flow within the wheel;

(*e*) the sliding action of the moving wall is likely to induce secondary motions in the main (relative) flow within the wheel, as well as the action of the fluid leaking through the clearance.

The increase of the flow loss in unshrouded impellers is probably the result of all these causes; some of them, however, must be predominant. Thus, in the case of the axial compressors, it appears to be established[1] that the tip loss is mainly due to the motion in the casing boundary layer, having a peripheral component higher than that of the main flow. In the case of radial wheels, on the basis of the somewhat scarce experimental evidence, the author has assumed that the controlling factor is the leakage. A comprehensive theory, taking all the possible causes of loss into account is, for the time being, an impossible task; on the other hand, the formulae that have been suggested so far to evaluate the increase of the flow loss in unshrouded impellers are, to the author's best knowledge, so roughly empirical that a tentative theory, however simplified, may not be entirely useless.

NOTATION

- b representative width of the meridional channel (Fig. 1)
- r radius
- L total length, in the meridional section, of the clearance between wheel and casing
- s clearance
- A meridional area of the blade
- S static moment of the meridional area of the blade with respect to the axis
- A_1 inlet section of the impeller
- l distance of a point of the clearance gap from the impeller inlet, measured on the meridional section
- z number of blades
- p pressure
- Δp pressure difference between both sides of a blade
- γ specific gravity of the fluid
- ω angular velocity of the wheel
- u_2 tip velocity of the wheel; $(=\omega r_2)$
- T torque exerted by the fluid in the wheel
- H_{ad} adiabatic head
- η_{ad} adiabatic efficiency
- $H = H_{ad} : \eta_{ad}$
- W weight rate of flow
- W_l weight leakage rate of flow
- c velocity
- V volumetric rate of flow
- g acceleration of gravity
- $\psi = 2gH/u_2^2$
- $\varphi = c_{1m}/u_2$
- $\eta_v = 1 - W_l/W$ volumetric efficiency
- μ flow coefficient of the leakage gap

Consistent units throughout

Indices:

- 1 wheel inlet
- 2 wheel outlet
- m meridional
- l leakage

THEORY

Let us consider a centrifugal compressor (Fig. 1); the pressure difference between both sides of a blade can be expressed by means of the torque exerted by the fluid on the wheel:

$$T = z\int_A r\Delta p\,dA \qquad T = \frac{HW}{\omega}. \quad . \quad (1)$$

As the distribution of Δp on the surface A is not known, we will assume that it is uniform so that:

$$T = z\Delta pS$$

$$\Delta p = \frac{HW}{\omega zS}$$

whence:
$$2g\Delta p = \frac{2gHW}{\omega zS} = \frac{\psi u_2^2 W}{\omega zS}. \quad . \quad . \quad (2)$$

Considering, unidimensionally, the fluid as having a (mean) definite specific gravity in any section of the fluid flow (b in Fig. 1), and assuming Δp to be small enough not to introduce compressibility effects, the velocity across the clearance is

$$\mu\sqrt{\left(\frac{2g\Delta p}{\gamma}\right)} = \mu\sqrt{\left(\frac{\psi u_2^2}{\omega zS}\frac{W}{\gamma}\right)} = \mu u_2\sqrt{\left(\frac{\psi}{\omega zS}\right)}\sqrt{V}$$

V being the volumetric rate of flow at the section b

$$V = c_m 2\pi rb.$$

The elementary weight leakage at the section b is:

$$dW_l = z dl\, s\gamma\mu u_2 \sqrt{\left(\frac{\psi}{\omega z S}\right)}\sqrt{V} = \mu s \sqrt{\left(\frac{z\psi}{\omega S}\right)} u_2 \sqrt{W}\sqrt{\gamma}\, dl$$

and the total leakage:

$$W_l = \mu s \sqrt{\left(\frac{z\psi}{\omega S}\right)} u_2 \sqrt{W} \int_0^L \sqrt{\gamma}\, dl. \quad . \quad (4)$$

Let us assume a linear relationship between γ and l:

$$\gamma = \gamma_1 + \frac{\gamma_2 - \gamma_1}{L} l$$

the integral is then easily solved

$$\int_0^L \sqrt{\gamma}\, dl = \frac{2}{3} L \gamma_1^{\frac{1}{2}} \frac{\left(\frac{\gamma_2}{\gamma_1}\right)^{3/2} - 1}{\left(\frac{\gamma_2}{\gamma_1}\right) - 1} \quad . \quad . \quad (5)$$

Now substituting equation (5) into equation (4):

$$W_l = \frac{2}{3} \mu s \sqrt{\left(\frac{z\psi}{\omega S}\right)} u_2 \sqrt{W} L \gamma_1^{\frac{1}{2}} \frac{\left(\frac{\gamma_2}{\gamma_1}\right)^{3/2} - 1}{\left(\frac{\gamma_2}{\gamma_1}\right) - 1}$$

and dividing W_l by the rate of flow through the impeller,

$$\frac{W_l}{W} = \frac{2}{3} \mu s L \sqrt{\left(\frac{z\psi}{\omega S}\right)} u_2 \frac{1}{\sqrt{V_1}} \frac{\left(\frac{\gamma_2}{\gamma_1}\right)^{3/2} - 1}{\left(\frac{\gamma_2}{\gamma_1}\right) - 1} . \quad (6)$$

As it is $$\frac{W}{\gamma_1} = V_1 = c_{1m} A_1 = \varphi u_2 A_1$$

and equation (6) becomes

$$\frac{W_l}{W} = \frac{2}{3} \mu \sqrt{\left(\frac{z s^2 L^2 r_2}{S A_1}\right)} \sqrt{\left(\frac{\psi}{\varphi}\right)} \frac{\left(\frac{\gamma_2}{\gamma_1}\right)^{3/2} - 1}{\left(\frac{\gamma_2}{\gamma_1}\right) - 1}$$

whence the volumetric efficiency of the wheel:

$$\eta_v = 1 - \frac{2}{3} \mu \sqrt{\left(\frac{z s^2 L^2 r_2}{S A_1}\right)} \sqrt{\left(\frac{\psi}{\varphi}\right)} \frac{\left(\frac{\gamma_2}{\gamma_1}\right)^{3/2} - 1}{\left(\frac{\gamma_2}{\gamma_1}\right) - 1} . \quad (7)$$

THE VALUE OF THE FLOW COEFFICIENT

When applying equation (7) to experimental results in order to assess the value to give μ, one must bear in mind that the leakage loss is higher than the comparison of the efficiencies of shrouded and unshrouded wheels would at first suggest, because the shrouded one presents a shroud friction loss and a loss due to the leakage from tip to entry along the shroud. This latter loss is not easily calculated, but it is possible to have an idea of the shroud friction loss, by using modern data on the friction of rotating wheels (*see* for instance Ref. 2).

By elaborating some experimental data in such a way, the author has found for μ, values around 0·3 and 0·4, which are below those measured in static test on the leakage through narrow slits. This may be due to the simplifying assumptions of the present theory, but it could also suggest that the motion of the blades actually reduces the leakage, possibly through the resistance of the boundary layer built up on the casing wall. The situation is quite different from the axial compressor case, where the leakage theory seems to give loss values lower than the actual ones. More experiment evidence is necessary to confirm the statements made here.

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Note on the Bending of a Finite Parallelogrammic Plate Under Continuous Non-Loading

by

K. I. McKENZIE, B.Sc., Grad.R.Ae.S., and M. ROTHMAN, M.Sc., Ph.D., A.F.R.Ae.S.

(The Northern Polytechnic, Holloway, N.7)

IN a previous note[1] the authors gave a method of solution for the problem of a finite rectangular plate under constant skew and inclined loadings, two of the edges being rigidly held and the other two simply-supported. In this note the same problem is considered for a plate in the shape of a parallelogram.

THE DIFFERENTIAL EQUATION

In this problem we make use of the oblique set of axes $O(x, y, z)$, where Oz is perpendicular to the plane of the plate and the angle xOy is α. The plate is assumed bounded by the lines $x=0$, $x=a$, $y=0$, $y=b$; the load on the plate is assumed to be F per unit area with components R, P, Q in the directions Ox, Oy, Oz respectively; and S and S' are taken to be the horizontal reactions per unit length along the edges $x=0$, and $x=a$ of the plate.

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Now consider a small parallelogrammic element of area $dx\,dy \sin\alpha$. If M_y, M_{yx}, Z_2 and Y are the bending moment, twisting moment, vertical shearing force, and horizontal force respectively per unit length acting on the edge parallel

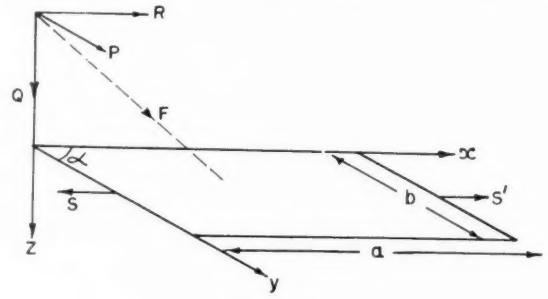

FIGURE 1.

to Ox, and M_x, M_{xy}, Z_1 and X are the corresponding quantities acting on the edge parallel to Oy, then taking moments about Ox and Oy for the element and equating the total downward load on the element to the vertical shearing forces; the following equations are obtained:

$$\left.\begin{aligned} \frac{\partial M_x}{\partial x}+\frac{\partial M_{yx}}{\partial y}\sin\alpha-\frac{\partial M_y}{\partial y}\cos\alpha+X\frac{\partial w}{\partial x}&=Z_1\sin\alpha\\ \frac{\partial M_y}{\partial y}-\frac{\partial M_{xy}}{\partial x}\sin\alpha-\frac{\partial M_x}{\partial x}\cos\alpha+Y\frac{\partial w}{\partial y}&=Z_2\sin\alpha\\ \frac{\partial Z_1}{\partial x}+\frac{\partial Z_2}{\partial y}&=Q\sin\alpha \end{aligned}\right\} \quad (1)$$

whence, eliminating Z_1 and Z_2,

$$\frac{\partial^2 M_x}{\partial x^2}+\frac{\partial^2 M_y}{\partial y^2}-\cos\alpha\frac{\partial^2}{\partial x\partial y}(M_x+M_y)+ +\sin\alpha\frac{\partial^2}{\partial x\partial y}(M_{yx}-M_{xy})+\frac{\partial}{\partial x}\left(X\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(Y\frac{\partial w}{\partial y}\right)= =-Q\sin^2\alpha \quad . \quad . \quad (2)$$

Now the bending and twisting moments are given by:

$$M_x=-D\left(\operatorname{cosec}^2\alpha\frac{\partial^2 w}{\partial x^2}+\cot^2\alpha\frac{\partial^2 w}{dy^2}- -2\operatorname{cosec}\alpha\cot\alpha\frac{\partial^2 w}{\partial x\partial y}+\nu\frac{\partial^2 w}{\partial y^2}\right)$$

$$M_y=-D\left(\cot^2\alpha\frac{\partial^2 w}{\partial x^2}+\operatorname{cosec}^2\alpha\frac{\partial^2 w}{\partial y^2}- -2\operatorname{cosec}\alpha\cot\alpha\frac{\partial^2 w}{\partial x\partial y}+\nu\frac{\partial^2 w}{\partial x^2}\right)$$

$$M_{yx}=-D(1-\nu)\left(-\cot\alpha\frac{\partial^2 w}{\partial x^2}+\operatorname{cosec}\alpha\frac{\partial^2 w}{\partial x\partial y}\right)$$

$$M_{xy}=D(1-\nu)\left(\operatorname{cosec}\alpha\frac{\partial^2 w}{\partial x\partial y}-\cot\alpha\frac{\partial^2 w}{\partial y^2}\right)$$

Also $$X=-(R+P\cos\alpha)x+S$$

$$Y=-(P+R\cos\alpha)y$$

thus writing $$R+P\cos\alpha=R'$$

$$P+R\cos\alpha=P'$$

and substituting in (2), the differential equation for the deflection of the plate under general continuous loading is.

$$\frac{\partial^4 w}{\partial x^4}+\frac{\partial^4 w}{\partial y^4}+2\frac{\partial^4 w}{\partial x^2\partial y^2}(\sin^2\alpha+3\cos^2\alpha)- -4\cos\alpha\left(\frac{\partial^4 w}{\partial x^3\partial y}+\frac{\partial^4 w}{\partial x\partial y^3}\right)+\sin^2\alpha\frac{(R'x-S)}{D}\frac{\partial^2 w}{\partial x^2}+ +\frac{R'}{D}\sin^2\alpha\frac{\partial w}{\partial x}+\sin^2\alpha\frac{P'y}{D}\frac{\partial^2 w}{\partial y^2}+\frac{P'}{D}\sin^2\alpha\frac{\partial w}{\partial y}=\frac{Q\sin^4\alpha}{D} \quad . \quad . \quad . \quad (3)$$

THE SOLUTION OF THE DIFFERENTIAL EQUATION

This problem differs from that of the rectangular plate in that the case of a load inclined to but parallel to one of the edges affords no simplification over the general case, since neither R', nor P' vanishes with P. Accordingly we shall deal with the general case only, from which any special case may readily be obtained.

Assuming a solution of the form

$$w=\sum_0^\infty\sum_0^\infty a_{m,n}x^m\sin\frac{n\pi y}{b}$$

which fulfils the boundary conditions on $y=0$, $y=b$ automatically, and substituting in (3):

$$\sum_0^\infty\sum_0^\infty\left\{(m+4)(m+3)(m+2)(m+1)a_{m+4,n}- -2(\sin^2\alpha+3\cos^2\alpha)\frac{n^2\pi^2}{b^2}(m+2)(m+1)a_{m+2,n}+ +\frac{n^4\pi^4}{b^4}a_{m,n}\right\}x^m\sin\frac{n\pi y}{b}+ +4\cos\alpha\sum_0^\infty\sum_0^\infty(m+1)\frac{n^3\pi^3}{b^3}a_{m+1,n}x^m\cos\frac{n\pi y}{b}- -4\cos\alpha\sum_0^\infty\sum_0^\infty(m+3)(m+2)(m+1)\frac{n\pi}{b}a_{m+3,n}x^m\cos\frac{n\pi y}{b}+ +\sin^2\alpha\frac{(R'x-S)}{D}\sum_0^\infty\sum_0^\infty(m+2)(m+1)a_{m+2,n}x^m\sin\frac{n\pi y}{b}+ +\frac{R'}{D}\sum_0^\infty\sum_0^\infty(m+1)a_{m+1,n}x^m\sin\frac{n\pi y}{b}- -\sin^2\alpha\cdot\frac{P'}{D}\cdot y\sum_0^\infty\sum_0^\infty a_{m,n}\frac{n^2\pi^2}{b^2}x^m\sin\frac{n\pi y}{b}+ +\sin^2\alpha\cdot\frac{P'}{D}\sum_0^\infty\sum_0^\infty\frac{n\pi}{b}a_{m,n}x^m\cos\frac{n\pi y}{b}=\frac{Q\sin^4\alpha}{D}$$

Using the Fourier expansions:

$$1=\frac{4}{\pi}\sum_{1\ r\,\text{odd}}^\infty\frac{\sin\frac{r\pi y}{b}}{r}, \qquad y=\frac{b}{2}-\frac{4b}{\pi^2}\sum_{1\ r\,\text{odd}}^\infty\frac{\cos\frac{r\pi y}{b}}{r^2}$$

$$\sum_0^\infty\sum_0^\infty\left\{(m+4)(m+3)(m+2)(m+1)a_{m+4,n}- -\left[2(\sin^2\alpha+3\cos^2\alpha)\frac{n^2\pi^2}{b^2}+\frac{S\sin^2\alpha}{D}\right](m+2)(m+1)\times \times a_{m+2,n}+ +\frac{R'}{D}\sin^2\alpha(m+1)^2a_{m+1,n}+\left(\frac{n^4\pi^4}{b^4}-\frac{P'}{2D}\sin^2\alpha\frac{n^2\pi^2}{b^2}\right)a_{m,n}- -4\cos\alpha\cdot c_{m,n}+\frac{P'\sin^2\alpha}{D}d_{m,n}\right\}x^m\sin\frac{n\pi y}{b} =\frac{4Q\sin^4\alpha}{\pi D}\sum_{1\ r\,\text{odd}}^\infty\frac{1}{r}\sin\frac{r\pi y}{b} \quad . \quad . \quad (4)$$

where

$$c_{m,n}=\frac{2}{b}\sum_{r\,\text{odd}}^{-\infty}\frac{1}{r}(m+1)(n-r)\left\{(m+3)(m+2)a_{m+3,n-r}- -(n-r)^2\frac{\pi^2}{b^2}a_{m+1,n-r}\right\}$$

$$d_{m,n}=\frac{2}{b}\sum_{r\,\text{odd}}^{\infty}\frac{n(n-r)}{r^2}a_{m,n-r}$$

where we take $$a_{m,-n}=-a_{m,n}.$$

Equating coefficients of

$$x^m\sin\frac{n\pi y}{b},$$

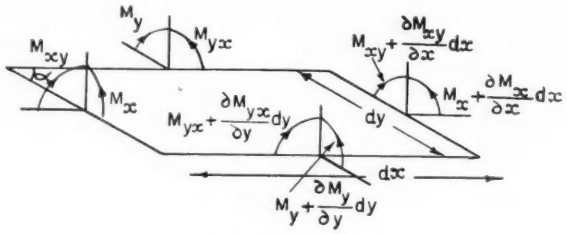

FIGURE 2.

for $m=0$

$$24a_{4,n} - \left\{ 2(\sin^2\alpha + 3\cos^2\alpha)\frac{n^2\pi^2}{b^2} + S\frac{\sin^2\alpha}{D} \right\} 2 \cdot a_{2,n} +$$

$$+ \frac{R'}{D}\sin^2\alpha \cdot a_{1,n} + \left\{ \frac{n^4\pi^4}{b^4} - \frac{P'\sin^2\alpha n^2\pi^2}{2Db} \right\} a_{0,n} -$$

$$- 4\cos\alpha \cdot c_{0,n} + \frac{P'}{D}\sin^2\alpha \cdot d_{0,n} = \frac{4Q\sin^4\alpha}{\pi Dn} \cdot \delta_n$$

where $\delta_{n=0}$ for n even, and $\delta_{n=1}$ for n odd.
For $m \neq 0$

$$(m+4)(m+3)(m+2)(m+1)a_{m+4,n} -$$

$$- \left\{ 2(\sin^2\alpha + 3\cos^2\alpha)\frac{n^2\pi^2}{b^2} + \frac{S\sin^2\alpha}{D} \right\}$$

$$\times (m+2)(m+1)a_{m+2,n} +$$

$$+ \frac{R'}{D}\sin^2\alpha (m+1)^2 a_{m+1,n} + \left(\frac{n^4\pi^4}{b^4} - \frac{P'\sin^2\alpha}{2D}\frac{n^2\pi^2}{b} \right) a_{m,n} -$$

$$- 4\cos\alpha \cdot c_{m,n} + \frac{P'\sin^2\alpha}{D} \cdot d_{m,n} = 0$$

From these relations for n and m as large as may be required, it is possible to find all the coefficients in the series for w in terms of $4n+1$ unknowns.

THE BOUNDARY CONDITIONS

I. If the plate is clamped along $x=0$, $x=a$, the boundary conditions are $w=0$ and $\frac{\partial w}{\partial x}=0$ on $x=0$, $x=a$; that is $a_{0,n}=0$ and $a_{1,n}=0$ all n, and

$$\sum_0^\infty a_{m,n}a^m = 0 \quad \text{and} \quad \sum_1^\infty m a_{m,n}a^{m-1} = 0 \text{ for all } n.$$

II. If the plate is freely hinged along $x=0$, $x=a$, the boundary conditions are $w=0$, $\frac{\partial^2 w}{\partial x^2}=0$, on $x=0$, $x=a$.

That is: $a_{0,n}=0$, $a_{2,n}=0$

$$\sum_0^\infty a_{m,n}a^m = 0, \qquad \sum_2^\infty m(m-1)a_{m,n}a^{m-2} = 0 \quad \text{for all } n$$

In each case the boundary conditions are sufficient to solve the problem completely except for the unknown S.

EVALUATION OF THE REACTION S

The change in the area of the plate as a result of bending is given by:

$$\Delta A = \int_0^a \int_0^b \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) dx\,dy \sin\alpha$$

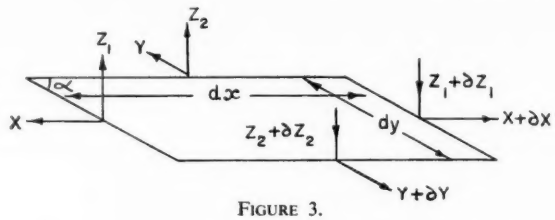

FIGURE 3.

where u and v are the components in the directions Ox and Oy of the point (x, y).

Now $\frac{\partial u}{\partial x} = \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2$ and $\frac{\partial v}{\partial y} = \frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2$

and the stress-strain relations in oblique co-ordinates give

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{1-\nu}{E}\left\{ \operatorname{cosec}^2\alpha\,(\overline{x}\overline{x} + \overline{y}\overline{y}) - 2\operatorname{cosec}\alpha\cot\alpha\,.\overline{x}\overline{y} \right\}$$

where $\overline{x}\overline{x}$, $\overline{y}\overline{y}$ are the normal stress components in the directions Ox and Oy respectively, and $\overline{x}\overline{y}$ is the component in the direction Oy of the shearing stress in a section of the plate parallel to the axis of y.
Therefore

$$\frac{1}{2}\int_0^a\int_0^b \left\{ \left(\frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2 \right\} dx\,dy \sin\alpha =$$

$$= \frac{1-\nu}{E}\int_0^a\int_0^b \left\{ \operatorname{cosec}^2\alpha\,(\overline{x}\overline{x} + \overline{y}\overline{y}) - 2\overline{x}\overline{y}\operatorname{cosec}\alpha\cot\alpha \right\} dx\,dy \sin\alpha \quad . \quad . \quad . \quad . \quad (5)$$

Assuming the variation of S along the edge $x=0$ to be second order and negligible, then if h is the thickness of the plate we have:

$$\int_0^b \overline{x}\overline{x}\,dy = \frac{bS}{h}, \quad \int_0^a \overline{y}\overline{y}\,dx = 0 \quad \text{and} \quad \int_0^a \overline{x}\overline{y}\,dx = \frac{S-S'}{h} = \frac{aR}{h}$$

Therefore substituting in (5):

$$\frac{S}{h} = \frac{E\sin^2\alpha}{2(1-\nu)ab}\int_0^a\int_0^b \left\{ \left(\frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2 \right\} dx\,dy +$$

$$+ \frac{2R}{h}\cos\alpha \quad . \quad (6)$$

and further substituting $w = \sum_0^\infty \sum_0^\infty a_{m,n}x^m \sin\frac{n\pi y}{b}$ we have:

$$\frac{S}{h} = \frac{E\sin^2\alpha}{4(1-\nu)\alpha}\sum_0^\infty \sum_0^\infty \sum_{r=0}^{m} \left\{ (r+1)(m-r+1)a_{r+1,n}a_{m-r+1,n} + \right.$$

$$\left. + \frac{n^2\pi^2}{b^2}a_{r,n}a_{m-r,n} \right\} \frac{a^{m+1}}{m+1} + \frac{2R}{h}\cos\alpha \quad . \quad (7)$$

so giving the final condition necessary for the complete solution of the problem.

REFERENCE

1. McKENZIE, K. I. and M. ROTHMAN (1955). Note on the Bending of a Finite Rectangular Plate under Continuous Non-Normal Loading. Technical Notes, *Journal of the Royal Aeronautical Society*, Vol. 59, March 1955.

The Lift on Wings at Sonic Speeds by Means of an Electrical Resistance Analogue

by

P. J. PALMER, Ph.D., M.Sc., A.F.R.Ae.S.

(*University of Birmingham*)

THIS note shows how a pure resistance analogue can be used to find the lift on low aspect ratio wings travelling, with small incidence, at speeds close to the sonic velocity.

The method is applicable to flat, twisted or cambered wings and is simple in operation; the results obtained being in close agreement with those obtained by calculations based on the same theory.

INTRODUCTION

The solutions given in this note are essentially those corresponding to the Jones[1] theory, which is applicable to low aspect ratio wings at small incidence, travelling with velocity close to the sonic value. Under these conditions it has been shown that the three-dimensional problem reduces to a series of two-dimensional problems in planes perpendicular to the direction of motion. Thus the wing can be considered as a series of spanwise sections, the solution for each section, in terms of the velocity potential, being considered in turn.

The relevant boundary conditions for the velocity potential are known provided that the sections are considered in turn starting with the foremost section at the apex of the wing plan form. From the velocity potential, the relevant aerodynamic properties can be rapidly deduced.

THEORY

Consider a wing in an air stream of velocity U, the wing axes x, y, z being as shown in Fig. 1, the x-axis being parallel to the wind speed direction. In accordance with the approximation referred to, the velocity potential ϕ satisfies the equation

$$\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=0 \quad . \quad . \quad . \quad (1)$$

provided that the incidence and aspect ratio are small, and that the wind speed is close to the sonic value.

Since ϕ is an odd function of z, only the region z positive need be considered. For any plane yz through the wing, the boundary conditions for ϕ on the y-axis are that $\partial\phi/\partial z$ takes prescribed values over the wing, ϕ takes prescribed values in the wake, and ϕ is zero elsewhere on the y axis. Also, ϕ becomes zero for large y and z.

The prescribed values for $\partial\phi/\partial z$ over the wing are proportional to the local incidence since

$$\frac{\partial\phi}{\partial z}=w=-U\,.\,\alpha_{\text{local}} \quad . \quad . \quad . \quad (2)$$

where w is the z component of the perturbation velocity and α_{local} is the local wing incidence.

The prescribed values for ϕ over the wake are those at the trailing edge since $\partial\phi/\partial x$ is zero in the wake for zero pressure in the wake.

METHOD OF SOLUTION

The method of solution by means of the electrical resistance analogue is indicated diagrammatically in Fig. 1. In this analogy the electrical potential is directly proportional to the velocity potential. The electrical resistance analogue used had a rectangular field with a separation of $1/64 \times 1/48$ giving a uniform square mesh. The resistances were each 100 ohms, except that the boundary resistances were each 200 ohms so as to make provision for axes of symmetry.

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For the experiments, the analogue was set up as follows. The network was short circuited and earthed on the y-axis outside the wing and wake, and also on the edge corresponding to large z. Over the wing the boundary potential was adjusted until the gradient assumed the prescribed value; this gradient being calculated over three ordinates by means of the formula

$$\left(\frac{\partial\phi}{\partial z}\right)_0=\frac{1}{2a}(4\phi_1-\phi_2-3\phi_0) \quad . \quad . \quad (3)$$

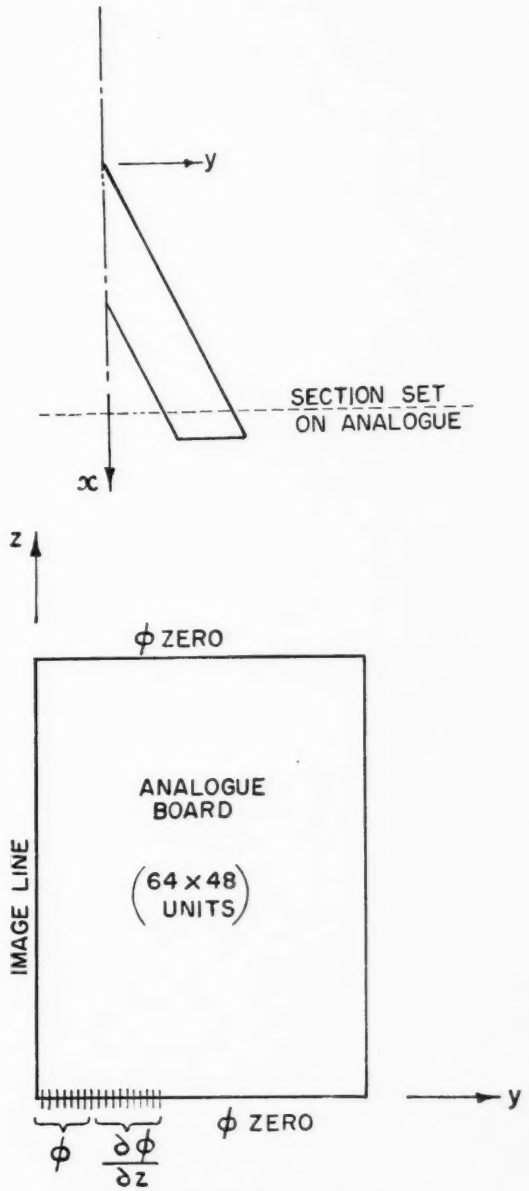

FIGURE 1. Analogue arrangement.

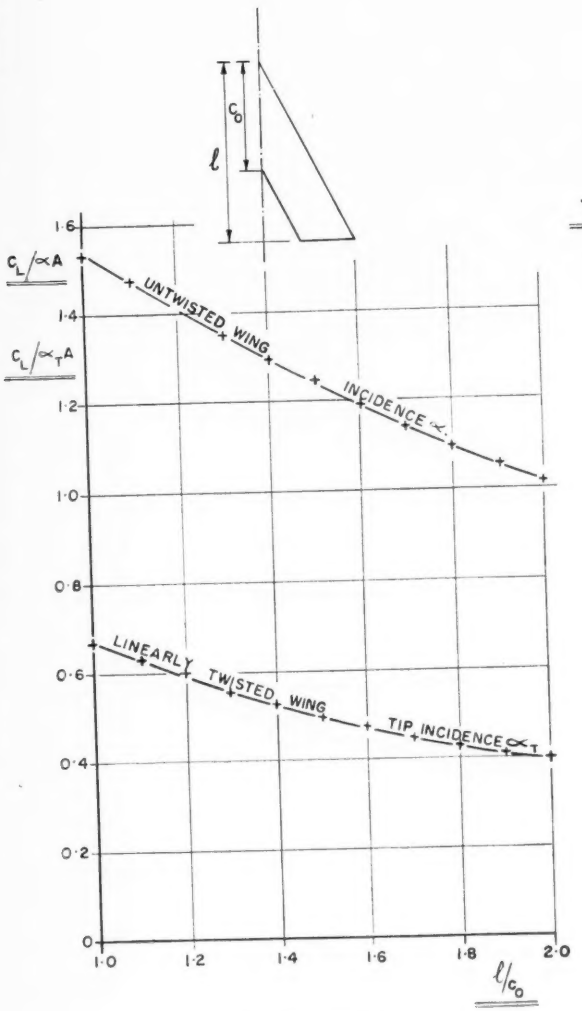

FIGURE 2. Lift coefficient.

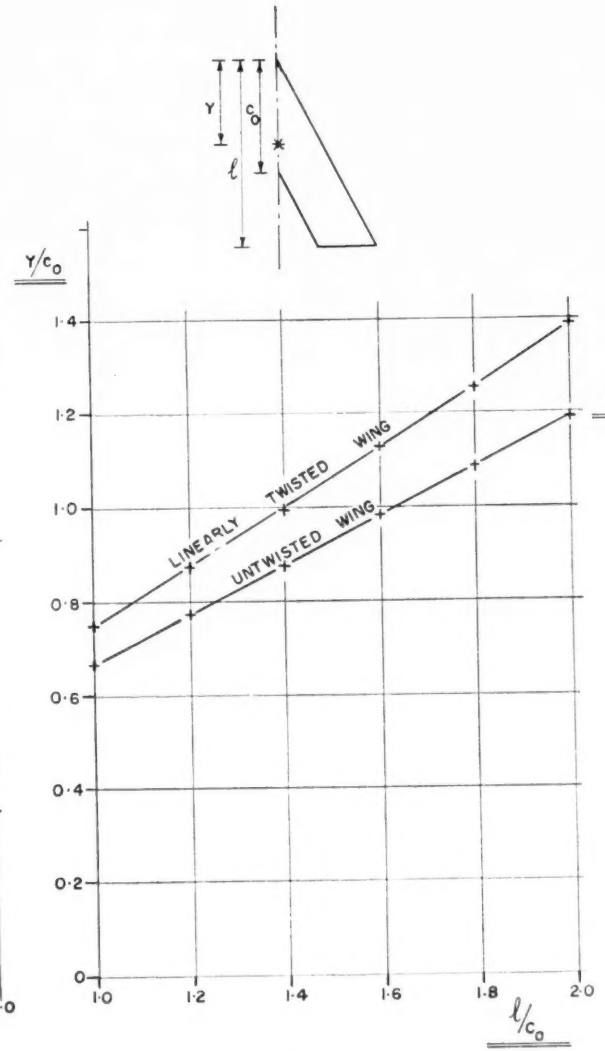

FIGURE 3. Centre of pressure.

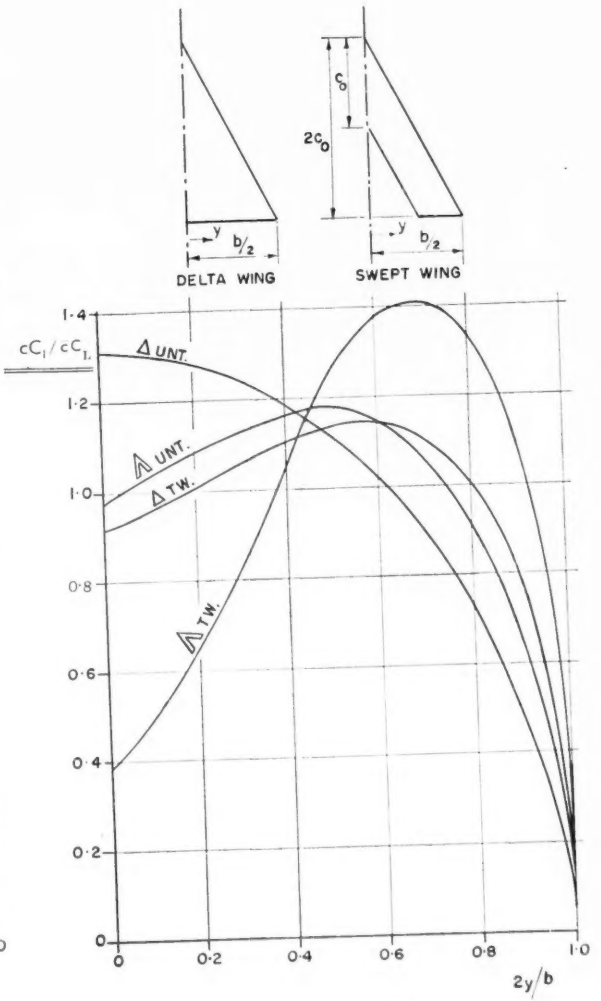

FIGURE 4. Spanwise loading.

where ϕ_0 is the boundary potential and ϕ_1 and ϕ_2 are the potentials at distances a and $2a$ respectively from the boundary.

If the section was such that part of the y-axis lay in the wake then the appropriate value of ϕ, as determined from the trailing edge of previously solved sections was applied.

The method has the advantage that it is applicable to plane wings, twisted wings, or cambered wings, with equal ease.

The aerodynamic properties may be deduced from the pressure difference across the wings, which is obtained from the formulae

$$\Delta p = -2\rho U \cdot \frac{\partial \phi}{\partial x} \quad . \quad . \quad . \quad (4)$$

where ρ is the air density. The full aerodynamic theory, together with the application to the electrical analogue, has been given in detail elsewhere.[2]

APPLICATIONS

By way of illustration, experiments were carried out on a series of plan forms such that the trailing and leading edges were parallel. This was done for both flat wings at incidence, and also for linearly twisted wings with zero root incidence.

The results are illustrated in Figs. 2, 3 and 4. Fig. 2 gives the lift coefficients for the various plan forms, where the results for $l/c_0 = 1$ correspond to those for a delta wing. Here, experiment gives $C_L/(\alpha A) = 1{\cdot}54$ and $C_L/(\alpha_T A) = 0{\cdot}664$ for a flat and twisted wing respectively, A being the aspect ratio. For comparison, theory[3] gives the values as being $\pi/2$ and $2/3$ respectively, showing that the analogue results are accurate.

Figure 3 gives the centres of pressures for the same family of wings and Fig. 4 gives the spanwise load distributions for the extreme cases of the family.

Broadly speaking these results show that the analogue is an accurate and simple method of producing the lifting properties of flat, twisted, or cambered wings in accordance with the Jones' approximation.

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Pilot Training

by

WILLIAM COURTENAY, O.B.E., M.M., A.R.Ae.S.

THE ADVENT of the jet transport age both for commercial and military aircraft will require conversion to jet training for pilots of all types of transport aircraft. This is the time therefore when consideration ought to be given to some comprehensive scheme on an Empire-wide basis for future recruitment and training of Pilots to a common standard.

It is not enough to assume that the needs of commercial aviation will be supplied by the Royal Air Force. There are two sound reasons why reliance on such a flow will prove erroneous. Firstly the training of the R.A.F. Transport and Bomber pilot is much akin to the requirement for the commercial airline, and once Air Forces have trained their long distance pilots they will make a career sufficiently attractive to induce the pilot to stay. Transport Command of the R.A.F. has already inaugurated such a scheme. It is based on the wise philosophy that experience cannot be purchased and that a pilot who has accumulated 3,000 hours of flying on four-engined aircraft is worth his weight in gold. So Transport Command plans to keep them all by offering attractive pay—even without promotion—to the age of, perhaps, 50 with, then, a pension. Bomber Command is likely to follow suit on the grounds that its aircraft each cost as much as a 1914 battleship; that they will be few in number; that they must not too easily be regarded as expendible; that we cannot afford to lose any in training or in peacetime operations; and, that once a pilot has acquired even 1,000 hours safe flying experience on such types as the *Victor*, *Vulcan* or *Valiant*, Bomber Command cannot afford to lose him. It will prove cheaper to keep him, even if his rank has to be frozen, beyond the usual flying age because as the years go by he will accumulate up to 5,000 hours priceless experience.

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On this supposition, which will prove cheaper and more attractive to the Royal Air Force than changing the youngsters each few years in Bomber Command, and more attractive to pilots passed over for promotion, there will only be a trickle available from R.A.F. channels for commercial aviation. Also, in 15 years time if the Guided Missile has taken over from the manned bomber, there may be no bomber pilots.

There is an even greater reason. The time may be coming when the monopoly exercised on ocean routes by State-aided Corporations is ended; when enough air liners are available in the 500 m.p.h. to 600 m.p.h. class, say by 1965, private enterprise may be given its head. Competition from the non-scheduled companies in the U.S.A. will force it upon us whether we wish it or not. They will offer Atlantic crossings at 99 dollars. They already carry passengers for 3,500 miles non-stop in four-engined air liners across America from Los Angeles or San Francisco to New York for 99 dollars. The distance is the same as an Atlantic crossing; fuel consumption for a comparable machine is comparable and they do not receive air mail contracts or subsidies, yet they make profits.

The 99 dollar, or £25, fare for an ocean flight from the United Kingdom to Montreal and New York is coming, even if not until 1965. If the jet air liner is available in abundance by 1960-62 then the discarded piston-engined air liners may be snapped up by private enterprise firms to inaugurate cheap-fare services by 1962. When it is possible to fly from the United Kingdom to Canada or the U.S.A. and back for £50 this will unleash such a vast volume of applicants for passage that all air liners will be filled; many more air liners will be required and many more Pilots and air crews. The Royal Air Force will not be able to keep up with the demand and may find it difficult to supply all the needs of Transport

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Command because by 1960, if the 100-seater 550 m.p.h. troop transport is available, all trooping will probably be undertaken by air.

By 1965 it will be pilot shortage not aircraft shortage which will plague the air lines. Shortsightedness and timidity of approach where imagination and boldness are required will be the cause.

Surely the answer lies in a grand plan based on a Commonwealth and Empire foundation for the recruitment and training of Pilots, Navigators, engineers and—where required these days—radio operators, for all types of jet and prop-jet commercial air liners. An Air University such as I visualise should include training on landplanes and flying boats. When the right engines are available perhaps the 'Princess' class flying boats will be re-engined; between 1960 and 1970, and onwards, the flying boat has a future on long-range Empire routes.

Such an Air University might well be sited in, say, Australia near Sydney where both land and sea flying facilities exist.

The high standard of perfection which such an Air University would aim at would become the envy of the world like the Central Flying School and other R.A.F. Establishments. It would become the "Trinity House" of the air.

At this Air University, youths of good education could be enrolled from all parts of the Commonwealth and Empire as Air Cadets at 16 years of age. Their first two years could be devoted to rounding off their education to a common pattern and to teaching them something of aeronautics, such as theory of flight, care and maintenance of jet engines, instruments and so on. They might never enter an aeroplane until they were 18 when full training would begin; by the time they were 21 they would pass out of the "Trinity House" Air University as Third or Fourth Officers with an all-round aeronautical education, with a Diploma, with a minimum of 1,000 hours of priceless experience acquired on many types of aircraft; with many dummy and actual runs on world routes in flying classrooms as part of their training.

As they will be in command in due course of 600 m.p.h. air liners each worth up to a million pounds and each carrying 100 to 130 passengers, it is essential that risks of pilot error be reduced as near to nil as possible; and that each be so well trained to a common pattern that he will be largely accident-free in his career. If all are turned out to a common pattern and standard it follows that all could be interchangeable on world air routes on all airlines operated by Commonwealth and Empire companies and Corporations.

As new types of aircraft entered service, each airline would be spared the costs of running its own training school; pilots would take refresher and conversion courses at the "Trinity House" Air University—again to a common standard of tuition. It would well repay us to ensure that no Pilot was hired, even by small 'non-sked' or obscure companies or by charter firms unless he held the Diploma of the University. A bad crash by a small company affects the good name and repute of the manufacturer of the aircraft, of the profession of the Pilot, of confidence in air travel. In time underwriters might insist no Pilot be hired for any task unless he had qualified and been kept up to date at the Air University.

The cost of such an Air University should be shared initially among all the Empire Governments, the purchase and development of the Base, of a 15,000 ft. airstrip with an adjoining flying boat base and all essential buildings. All new high speed aircraft could be tested on the University airstrip, so it could serve a double purpose.

What if the capital outlay of such a plan did involve some £100,000,000? What does the cost matter? We would be building something which, like seamanship, would last for a thousand years or more. It would well repay Great Britain to find all the capital costs, if all the Dominions and Colonial Governments paid an agreed share of annual maintenance, staff salaries, bursaries, scholarships, and so on.

With such a plan for a common heritage of recruitment and training an ample flow of pupils would be assured; an assured career for pilots, ground crews and air crews would be provided with the ladder safe from 16 years of age to 45 or 50, and with a pension. This would attract all the personnel required. Because it is a waste of talent to end a pilot's active flying career when he is 45, a plan might be evolved whereby pilots could, if they wished, convert to Helicopters and spend at least ten more fruitful years, to the age of 55, flying the 50-seaters which should be available on short haul routes by 1965.

Even if all the Commonwealth and Empire accepted such a plan with enthusiasm and opened the purse strings in 1956 to begin work on it, it would probably be 1963 before the Base and all buildings were ready and before the first students could be accepted. And the 16-year-old youth then would be 21 before reaching an airline, even as Third or Fourth Officer—still not in command of a million pound 600 m.p.h. jetliner. That brings us to 1968. Thus even if we began training such youths in 1956 on a modest scale at some existing aerodrome it would be 1961 before they had 1,000 hours experience. There is not a moment to lose for by 1961 the jet liners ought, even on the most pessimistic calculations, to be flowing from the assembly lines. If by 1962 cut-rates could operate on the Atlantic at £25 for a cheap fare it may already be predicted that while enough aircraft may be ready, there will be a shortage of pilots. Such a scheme ought to have been inaugurated five years ago so that by 1960 there would be a steady flow of highly trained jet transport pilots available for the great expansion of air travel which lies before us.

With such a plan as this University of the Air, the old vision of an Imperial Airways could be resurrected; if each country in the Commonwealth controlled its own internal domestic air services, if all Commonwealth pilots, air and ground crews were trained to a common pattern and were interchangeable round the world, then each member-country could be assured of its fair quota of posts and postings. Thus a true Imperial routing could be assured for all overseas flights across oceans; the profit motive should be the strongest urge behind it and all countries share the pool of profits to an agreed plan.

What a grand conception this would be; what a wonderful aid to Empire commercial aviation; to assured careers for thousands of young men from all over the Commonwealth and Empire; and what a comfort and blessing to every airline operator. Even the differences required by airlines in training or passenger handling could be catered for at the Air University so that every need was met.

That the employment from 1965 onwards will run into thousands—not hundreds—is assured. Only the timid and fainthearted who do not perceive the glorious future awaiting commercial aviation, will be content to think otherwise or to place reliance for all Pilot requirements on an uncertain trickle from the R.A.F.

THE LIBRARY

Reviews

MORALE IN WAR AND WORK. *Dr. T. T. Paterson. Max Parrish, London 1955. 256 pp. Illustrated. 18s.*

Dr. Paterson endeavours to provide the basis for the solution of industrial relations problems on the basis of a careful, statistical and scientific study of some Air Force units in which he was stationed during the war. The nature of the approach is interesting in that Dr. Paterson had an unexpected opportunity to investigate group psychology when he was posted as a Controller to the station of " Bogfield " during the war.

The Commanding Officer, who appears to have been singularly enlightened, asked him first to investigate the cause of a series of accidents, mostly during normal landing and take-off, which had been occurring and which raised this squadron's record in this respect well above the accident level of the rest of the R.A.F.

Dr. Paterson soon discovered that the station was afflicted by widespread bad morale and the main part of the book is devoted to analysing this and converting the simple day-to-day phrases indicating conflict into sociological language and in " typing," that is to say, categorising individual officers into their sociological types.

In addition to this analysis (which as far as this book is concerned could not go to any great depth) Dr. Paterson was led to try experiments based on the idea that morale would be built up by introducing conflict with some enemy and, since the German Air Force was not available in sufficient force at that time, he substituted the weather.

The experiment proved to be very successful in cutting down the recorded accident rate and, accepting the statistics as really significant, this is an interesting and useful piece of work.

After an analysis of the results of the " Bogfield experiment, Dr. Paterson applies some of these results to industrial activities in the Coal-mining and manufacturing field and recognises to a limited extent in industry the same types and the same phenomena which were discovered in the R.A.F. during wartime. The same type of reaction to the " in " and " out " groups is detectable in the Coal Industry, the same status approach to problems where the actual coal-cutter is regarded as the most important man having the highest status in the industry forms a close parallel with the pilot group in the R.A.F.

The work is written in an entertaining style and contains a great deal of the elements of the reminiscences of a war book. The language of the R.A.F. is reported colloquially and the small historical details are, in themselves, of considerable interest. The whole work, viewed in retrospect, gives the impression of being a piece of applied common sense, supported by a limited amount of measured data.

This, however, is almost the universal situation to be faced by any worker in the field of group psychology, for the simple reason that controlled and confined experiments are enormously difficult to organise and the circumstance under which they are likely to occur is so limited that the data of a statistical nature must always be unsatisfactorily meagre. Nevertheless, the book is well worth while reading even if the reader accepts it with healthy scepticism in so far as it propounds general theories or principles. The value lies in a general indication of the possibilities of the application of this type of thinking to experiments which can relatively easily be performed and which may produce results out of all proportion to the magnitude or cost of the arrangements necessary for the tests.

This is indicated by the differences in accident rate during the currency of the experiment and, indeed, the corresponding drop in the illness rate of the W.A.A.F. (women) when operations of some interest were run and where the girls were integrated into the experiment and had an object in life in doing their routine work.—J. V. CONNOLLY.

ROTORCRAFT. *Capt. R. N. Liptrot and J. D. Woods. Butterworths Scientific Publications. London, 1955. 161 pp. Illustrated. 32s.*

The authors of this book set out to explain " the fundamentals of rotorcraft engineering in a simple and practical manner." This is a most welcome objective forming a refreshing contrast to the complicated symbolism around which many reports are written. The book may well help to clear away the suspicion with which helicopters are still regarded by many aircraft engineers. Rotorcraft are no longer of interest to initiates only.

The first chapter is historical, and a number of fascinating pictures show designers groping towards a successful vertical flight machine. It will surprise many readers to see how long ago these attempts were being made. Another useful source of information is the bibliography given at the end of the book. This bibliography, together with its very thorough system of cross references, will ease the task of any student searching for information.

A simple method of performance estimation is developed *ab initio*. The full analysis of a helicopter rotor is most complicated and drastic simplification must be made to achieve a workable result. It is inevitable therefore that empirical expressions play a large part in this method. No attempt is made to justify these expressions rigorously, and one assumes that they have been derived by " tailoring " the analysis of flight test results and by appeal to physical intuition. On the other hand this criticism could apply to any performance method, the difference is one of degree only. The method quoted gives quick and reasonably accurate results and this goes a long way towards justifying it.

The authors have not perhaps been too successful in attaining their objective of simplicity in the dissertation on the articulated rotor. The subject is difficult and the chapter repays careful study, but it is highly condensed and sometimes a little cryptic. Rather than give a coherent picture to a beginner, the authors have tended to explain specific points. Sometimes these points are oddly chosen, as when it is shown from first principles that the Coriolis acceleration is $2\dot{r}\dot{\theta}$. Again an occasional misprint occurs in the mathematics and from the several axes of reference some symbols emerge undefined. In later editions this chapter could with advantage be expanded.

Other chapters include a useful introduction to stability control systems and design study procedures, and attention is also given to operating costs, comparing helicopters with fixed wing aircraft.

It is difficult to generalise about this book. Necessarily it covers a wide field so a review tends to be rather fragmentary. There is no doubt however that it fulfils a need and should form a useful introduction to the rotating wing field.—D. M. DAVIES.

THE THIRD SERVICE. *Air Chief Marshal Sir Philip Joubert, K.C.B., C.M.G., D.S.O. Thames and Hudson Ltd., London. 1955. 274 pp. 32 illustrations. 21s.*

In his Foreword, Air Chief Marshal Sir Philip Joubert writes, "The book is intended as a study of interservice jealousies and the perils they incur and as a warning to the British people of the risks that are involved in allowing these jealousies to obscure sound judgment."

> "Oh, beware, my lord, of jealousy;
> It is the green-ey'd monster which doth mock
> The meat it feeds on."

Sir Philip Joubert has played a great part in the Royal Air Force and has that independence of character for which much may be forgiven in a world of mass-manufactured mediocrities. But he has not been able to hide his own jealousies of the Admirals and the Generals, particularly of the former.

His pen is filled with vitriolic green ink; though, when it runs dry and waits refilling, he uses one which has been dipped in a little soothing syrup, but doesn't last so long.

". . . and again when I was at the Imperial Defence College, the interservice battle between the Navy and the Army on one side trying to destroy the integrity of my service and the R.A.F. struggling for survival on the other, was in full swing. No punches were pulled and no stones that could be thrown were left unused. . . ."

There is "lack of imagination" in those who do not press for the Air Force, the whole Air Force, and nothing but the Air Force. The author's comments about well-known and not so well-known personalities in all three Services and the Government reveal much of his own captious-cum-commendatory personality.

"After my return from S.E.A.C. I warned the Chief of the Air Staff that, in my opinion, the Battle of Whitehall was due once again to start. . . . From the moment hostilities ceased the Royal Navy re-opened the attack, and throughout the years the spate of lectures, letters and articles flowing from the mouths and pens of retired admirals, and undoubtedly inspired from Whitehall, has never ceased and today has become a flood. . . . Already, as a result of the development of the R.N.A.S. and the evolution of the modern form of war at sea where the C-in-C Home Fleet may command the forces from a dug-out on Portsdown, there are more Admirals ashore than afloat. Soon, if this development proceeds much further, their lordships will not be Sea Lords but Land Lords."

This is not worthy of an Air Chief Marshal, Sir Philip.

In October 1942 the gallant Chief Marshal, "thoroughly exasperated at the manner in which the U-boat campaign was being waged," wrote a paper and presented it to the First Sea Lord. "Its reception was frigid."

The polite version of the paper is given in Appendix VI.

There is much in this book which has, one feels, been written in haste and may be repented at leisure. It is a book which many will enjoy, and many will not, depending upon agreement or not with the author's final statement on page 245 that the real defence of Britain lies with the Royal Air Force.

The new call up will presumably be called The National Air Service.

The Air Chief Marshal must have read Dr. Johnson's "Rasselas."

". . . I have been long of opinion . . . that the fields of air are open to knowledge, and that only ignorance and idleness need crawl upon the ground."—J. LAURENCE PRITCHARD.

HYDRAULIC AND PNEUMATIC OPERATION OF MACHINES. *H. C. Town. Odhams Press Ltd., London. 1955. 192 pp. Illustrated. 21s.*

It is unfortunately necessary to say right away that this is not a book which can be recommended. It attempts to cover comprehensively the fairly wide field of fluid operation of machine tools and machinery in general, although not, be it noted, aircraft equipment. The Author is the head of a department of a well-known Technical College and as such must be expected to maintain a high standard of accuracy and comprehensiveness in his writings.

The book starts off by an explanation of the "hydraulic paradox" which is usually ascribed to Pascal but the first page contains a glaring error (could it be called a printers mistake?), where

$$P = \frac{p \times A}{a} \quad \text{is printed as} \quad P = \frac{A}{p \times a}.$$

The Author cannot be forgiven for talking of pressures when he means loads ("a pressure of 10 lb.") nor indeed loads when he means pressures ("a load of 1,000 lb. per sq. in."). These mistakes on the first two pages can hardly encourage the reader to carry on.

There are other minor faults in the book; for example: pressures in pound-inch units are referred to in one place and metric units in others; Lamé without the accent; the statement that aircraft operate over ranges of temperature from 65 to 165°F (obviously −65°F is meant); on page 182 we read that "the methonal bottles remove impurities" (methonal bottles are used to prevent freezing of pneumatic systems); a most confusing habit of numbering the figures in each Chapter from 1 onwards without prefixing with the number of the Chapter so that the book contains various figures with the same number.

Apart from the detailed faults referred to above there are a number of major criticisms which can be made. For example the whole of the field of aircraft actuation is covered by a short section dealing with pneumatics and hydraulics in a Chapter labelled "Industrial Applications of Pneumatic Power". The broad and fascinating subject of the application of hydraulics and pneumatics to servo-mechanisms used for tracer control of machine tools is dismissed in less than a page in a Chapter labelled "Hydro-Pneumatic Operation". In a book of this nature adequate sections on seals and pipe losses could be expected; the former gets half a page and the latter six lines. Again the important matter of valve gear—although it has a Chapter to itself—is treated in a manner both confusing and complicated to the inexpert, in two pages, no attempt being made to sort out the basic differences in the many types of known valve.

There is, however, much of value in the book. Some of the information on machine tool applications is of interest although many sections would appear to be based upon manufacturers' literature. A particularly valuable section deals with pneumatic tools and the use of standardised pneumatic components for the operation of jigs and fixtures; this Chapter is illustrated by some excellent diagrams.

The book as a whole gives evidence of having been prepared without the thoroughness that one would expect from someone of the reputation of the Author and although the standard of printing and the clarity of the diagrams are commendable the book as a whole is disappointing. The aircraft engineer particularly will find little of value in it.—H. G. CONWAY.

JAHRBUCH 1954 DER WISSENSCHAFTLICHEN GESELLSCHAFT FÜR LUFTFAHRT. *Edited by Prof. H. Blenk. Vieweg and Sohn, Brunswick, 1955. 324 pp. Illustrated. 36 DM.*

This "Year book" is the third since the post-war inauguration of the W.G.L. in 1952. As well as general reports of the society's activities, it contains the lectures delivered at the Congress in Duisburg in October 1954. Most of the 45 papers are in German, with summaries in English and French. The remainder are in English, with summaries in the other two languages; they are by H. J. Allen on N.A.C.A. transonic wind tunnels, by C. H. E. Warren on transonic air flow, by E. R. van Duist on boundary layer heat transfer, by A. E. Raymond on turbine transports and by L. Broglio on vibration in high-speed aircraft structures. There is a complete section of 13 papers (in German) on aviation medicine.

AIRCRAFT TODAY. *Edited by John W. R. Taylor. Ian Allan, London. 1955. 96 pp. Illustrated. 9s. 6d.*

The editor has collected authors who are well-known as writers in various spheres of aeronautics and put them together to form this second volume of what is intended as an annual. The text makes it difficult to assess the intended audience. Not technical, not elementary and not completely general interest; then what? The Introduction provides the clue. "There was no annual publication which would keep . . . different classes of reader—and the businessman who has no time to read the aeronautical weeklies—informed about all the latest developments in the world of aviation." The author may be right but I feel that this is another of those books which will appeal to the A.T.C. and the interested 14 plus.

TABLES OF THE CUMULATIVE BINOMIAL PROBABILITY DISTRIBUTION. *By the Staff of the Computation Laboratory. Harvard University Press. London: Cumberlege, 1955. 554 pp. 63s.*

This volume contains over 500 pages of tables (to six decimal places) of the mathematical function which represents the probability that at least r successes will occur in a given number of tries. It is expected to be useful to statisticians interested in problems relating to sampling and quality control and includes 50 pages of introduction showing the uses of the function tabulated.

BOUNDARY LAYER THEORY. *H. Schlichting. Translated by J. Kestin. Pergamon Press, London, 1955. 535 pp. Illustrated. £5 5s.*

When the original German edition of this book was reviewed in the JOURNAL of November 1951 (p. 747), the reviewer concluded: —

"For aeronautical engineers who read German this book should prove valuable both as a textbook and as a reference book. For the sake of those who do not read German it is to be hoped that the book will be translated into English soon enough for it not to be out of date when issued."

The English edition has now been published, but it is not a literal translation of the German. Taking into account the progress made since 1951, the author has completely rewritten two chapters and has made many smaller additions. The book was written primarily for engineers working in industry and in research establishments and for students of mechanical engineering and machine design. It evolved from lectures delivered by the author at the Technical University of Brunswick.

CONTROL OF INSECT VECTORS IN INTERNATIONAL AIR TRAFFIC. *World Health Organization. 1955 (obtainable from H.M.S.O.). 59 pp. 3s. 6d.*

In this pamphlet is summarised much of the requirements of the world in the matter of disinfestation, or disinsection, as this pamphlet calls it—both horrible words anyway. The carriage of a couple of 'flu germs by jet propulsion has possibilities in epidemic spreading with which our forefathers did not have to cope and all sorts of lethal insects have distressing habits in egg-laying where aircraft are concerned. Not all countries have disinsection requirements at the moment and the regulations are, of course, most stringent where you have such creatures as *Paratriatoma hirsutus* and *Stegomyia.*

The implications of spraying may be distasteful to the readers of this review but one has only to think of the way rabies has been eradicated in this country to realise that a momentary personal inconvenience may well save a nation from a decimating epidemic.

NUCLEAR PHYSICS. *Irving Kaplan. Addison Wesley Publishing Company, 1955. 609 pp. Illustrated. $10.*

The purpose of this book, written by the Senior Physicist at Brookhaven National Laboratory, is to provide an introduction to nuclear physics for engineers, physicists, chemists, and other scientists who must have some familiarity with the subject.

The level of presentation is that of an advanced undergraduate course, and it is assumed that the reader has a general background in classical physics and a working knowledge of calculus. However, no previous knowledge of either atomic or nuclear physics is needed.

The book is divided into three parts: Part I, consisting of seven chapters, is devoted to the background of nuclear physics. It begins with the chemical foundations of atomic theory and covers such subjects as radioactivity, X-rays, atomic structure, atomic spectra, and relativity. Part II, containing ten chapters, treats the physics of the nucleus. Part III, five chapters, deals with special topics and applications, including neutron physics and nuclear fission, which lead to a consideration of nuclear energy, together with charged-particle accelerators and isotope separation, which form the main part of nuclear engineering.

STATIC AND DYNAMIC ELECTRON OPTICS. *P. A. Sturrock. Cambridge University Press, 1955. 240 pp. Diagrams. 30s.*

This book is the fourth in the Cambridge series of Monographs on Mechanics and Applied Mathematics and has the sub-title "An Account of Focusing in Lens, Deflector and Accelerator." In writing it the author had in mind the needs not only of those already engaged in research and development who wish to calculate the properties of some new instrument or machine, but also of scientists who are not yet familiar with the subject and therefore look to a theoretical exposition for an account of the ideas common to all applications. Part I, on static electron optics, deals with the focusing of charged particles in static electromagnetic fields. Part II, on dynamic electron optics, is devoted to the focusing of charged particles in time-dependent electromagnetic fields as realised in particle accelerators. The tendency has been, for reasons explained by the author, to emphasise the optical rather than the dynamical aspect of these problems.

FLIGHT FLY-PAST. *"Flight" Cameramen. Iliffe, London, 1955. 24 photographs. 7s. 6d.*

To one who has the greatest difficulty in getting a likeness of his family, static, with a box-camera, the efforts of those who get sharp outlines of near-supersonic aircraft on a background of clearly defined landscape or seascape are nothing short of miraculous. The two *Flight* staff photographers here give 22 examples of these miracles. If there is any beauty in technical perfection, these photographs *must* be beautiful.—F.H.S.

200 MILES UP. *J. Gordon Vaeth. Second Edition. Ronald Press, New York, 1955. 261 pp. Illustrated. $5.*

The first edition of this book was reviewed in the Journal for December 1951 (p. 808), where it was strongly recommended to anyone wanting to obtain a general picture of the present position on upper-atmospheric studies. This second edition gives an account of the American programme of upper air research and relates the programme to its latest development, the artificial satellite. Three new chapters have been added: "The Future and the Upper Air", "The Minimum Satellite" and "Beyond the Earth."

AIRCRAFT BADGES AND MARKINGS. *Harold B. Pereira. Adlard Coles, Southampton, 1955. 48 pp. Illustrated. 5s.*

Lord Douglas starts his foreword to this little book by describing it as filling a long-felt want and this rather hackneyed phrase is, for a change, justified—particularly to harassed parents living on the air lanes. When the cloud base is low enough, plane-spotting for the youngsters has the added hazard of Marking-distinguishing and this book has all those the h.ps are likely to want and many more besides. Next time an aircraft flies over my house with the Code Letter AN I shall know that it comes from Nicaragua and if it hasn't a tail with blue and white lateral stripes emerging from a vertical yellow band and a red circle containing a white triangle on a blue base on its fuselage I shall want to know the reason why. Mr. Pereira has either done an awful lot of travelling or written a great many letters but the resultant collection of exotic Civil Airline badges has made it well worth while. The only drawback to such a collection is that by comparison B.O.A.C. looks almost naked. Hongkong Airways, for instance, would look much nicer on an English airlines machine.—F.H.S.

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Reports

AERODYNAMICS

Compressible Flow

Effect of variable viscosity and thermal conductivity on high-speed slip flow between concentric cylinders. T. C. Lin and R. E. Street. N.A.C.A. Report 1175 (1954).

The differential equations of slip flow, including the Burnett terms, were first solved by Schamberg assuming that the coefficients of viscosity and heat conduction of the gas were constants. The problem is solved here for variable coefficients of viscosity and thermal conductivity by applying a transformation leading to an iteration method. The method, starting with the solution for constant coefficients, enables one to approximate the solution for variable coefficients very closely after one or two steps.—(1.2.3 × 1.1.0).

Loads

*Strip theory for oscillating swept wings in compressible subsonic flow. W. Eckhaus. N.L.L. Report F.*159 (*Oct.* 1955).

By an asymptotic expansion, valid for high aspect ratio and a not too low frequency, a strip theory is derived, which can be expected to possess the same accuracy as the usual two-dimensional approximation for straight wings. It is shown that according to this strip theory the pressure consists of the two-dimensional pressure, multiplied by a factor cos ϕ (ϕ being the section angle of sweep) plus an additional pressure, which follows from an equation of the Poisson type, and which is only zero if ϕ is zero, or if the wing is infinitely long. In the limiting case of incompressible flow the theory is shown to lead to results identical with earlier results for that case. Methods of computing the pressure distribution from the integral equation of the strip theory are indicated and discussed.—(1.6.3).

Performance Estimation

General solutions of optimum problems in nonstationary flight. A. Miele. N.A.C.A. T.M. 1388 (*Oct.* 1955).

A general method concerning optimum problems in non-stationary flight is developed and discussed. Various conditions of flight in a vertical plane (climb with minimum time, climb with minimum fuel consumption, steepest climb, descending and gliding flight with maximum time of space) are studied; the corresponding best techniques of flight, that is, the optimum speed-height relationships, are determined.—(1.7).

Wings and Aerofoils

Calculation of the pressure distribution over a wing at sonic speeds. K. W. Mangler. R. & M. No. 2888 (1955).

A method is developed for the calculation of the pressure distribution and the aerodynamic forces and moments acting on a wing at incidence, a wing in (steady) roll and a wing in (steady) pitch. The calculation is based on the assumption of an inviscid potential flow and is restricted to small incidence and thickness ratio, so that quadratic terms in the perturbation velocities are neglected. The results are valid, if $A^2(1-M^2)$ is small compared to 1. The aerodynamic coefficients and stability derivatives l_p and m_q for a wing family which is described by the parameters aspect ratio A, taper ratio λ, and sweep ratio a, are given in the form of charts. The calculation indicates that the plan-form of the wing is of similar importance, as regards the pressure distribution at sonic speeds, as the chordwise section of a wing at subsonic speeds for wings of larger aspect ratios.—(1.10.1.2).

Helicopter Aerodynamics

Wind tunnel tests on a 6 ft. diameter helicopter rotor. T. B. Owen et al. C.P. No. 216 (1955).

Thrust, torque and flapping angle have been measured on a 6 ft. diameter rotor over a range of blade angle, shaft inclination and tip speed ratio for comparison with the 12 ft. diameter rotor previously tested in the 24 ft. tunnel. In addition to tests in the 24 ft. tunnel, the 6 ft. diameter rotor was also tested in the No. 2 11½ ft. tunnel to investigate tunnel constraint. Brief investigations were made of support interference and blade twisting.—(1.11.3).

Testing and Instruments

Automatic pressure measuring systems used with high-speed wind tunnels. C. L. Frederick et al. AGARDograph 10 (*June* 1955).

A brief review is given of high-speed wing tunnel characteristics with particular reference to instrumentation needs, followed by a survey of the major elements of pressure measuring systems. Representative pressure measuring systems in actual use in the United States are described.—(1.12.5).

Turbulence measurements with the hot-wire anemometer. R. D. Cooper and M. P. Tulin. AGARDograph 12 (*Aug.* 1955).

The contemporary status of turbulence measurements utilising the techniques of hot-wire anemometry is discussed. The motivations and objectives of current experimental turbulence research are indicated. Certain essential definitions and ideas of the statistical theory of turbulence are reviewed. A list of significant experimental investigations, including a brief description of important features of the experiments, is presented in tabular form.—(1.12.6).

AEROELASTICITY

Torsional vibrations of a class of thin, tapered, solid wings. E. A. Frost. C.P. No. 218 (1955).

The torsional vibrations of thin solid wings of doubly-symmetrical chordwise section, with linear variation of chord, and parabolic variation of thickness are considered. Frequencies of symmetrical and anti-symmetrical vibrations are presented graphically for a range of values of the aspect ratio and the taper ratio.—(2).

Some effects of system nonlinearities in the problem of aircraft flutter. D. S. Woolston et al. N.A.C.A. T.N. 3539 (*Oct.* 1955).

Results are given of a preliminary investigation of the effect of nonlinear structural terms on the flutter of a two-degree-of-freedom system. The three types of nonlinearities investigated were a flat spot, hysteresis, and a cubic spring. Calculations were made on an analogue computor. For one case, the flat spot, an experimental investigation was also made and good correlation with theory was found.—(2).

AIRCRAFT OPERATION

Crash-fire research with jet aircraft. I. I. Pinkel. I.A.S. Preprint No. 570 (*Nov.* 1955).

Research on the origin of crash fires, conducted by the N.A.C.A. from 1949 to 1953, covered aeroplanes powered with reciprocating engines (*See* N.A.C.A. Report 1133, and N.A.C.A. Technical Film 26). This report reviews the full-scale research with jet aircraft that followed the work with reciprocating-engine aircraft.—(5.3).

Aircraft accident investigation. R. C. Davis. I.A.S. Preprint No. 575 (*Nov.* 1955).

A number of accidents, their investigation and remedies are described and general conclusions are drawn on the steps necessary to ensure safety in flight.—(5.3).

Étude expérimentale et théorique de la décompression explosive et de ses effets physiologiques. F. Violette. Publications scientifiques et techniques. No. B.S.T. 118 (1955).—(5.3 × 9).

Pilot's loss of orientation in inverted spins. S. H. Scher. N.A.C.A. T.N. 3531 (*Oct.* 1955).

The rising problem of pilot orientation during spins, especially during unintentional inverted spins, is discussed.

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

The free-spinning-tunnel results and reported aeroplane experiences concerning inverted spins and recoveries are reviewed. Information is provided regarding the nature of inverted spins, optimum control technique for recovery, and some of the factors which apparently contribute to the pilot's loss of orientation.—(5.3 × 9).

AVIATION MEDICINE

See AIRCRAFT OPERATION

MATERIALS

Characteristics of plastic deformation on the surface and in the interior of a polycrystalline aluminium-silver alloy. N. A. McKinnon. A.R.L./MET. 2 (*March* 1955).

The use of silver solute atoms as markers for lattice disturbances remaining after the deformation of an aluminium-silver alloy is described. This has enabled the study of the metallography of deformation in the interior of test pieces of this alloy, whereas hitherto only surface effects could be investigated.—(21.1).

Materials and fabrication techniques for structural heat-resistant plastic sandwiches. N. E. Wahl. I.A.S. Preprint 571 (*Nov.* 1955).

This paper reviews some of the work carried out at the Cornell Aeronautical laboratory on non-metallic materials and their use in the production of structural sandwich wings. —(21.0 × 33.2.4.6.0).

Aluminum alloys for elevated temperature service. E. H. Dix, Jr. I.A.S. Preprint No. 574 (*Nov.* 1955).

Data is given on some new alloys with particular reference to their properties at elevated temperature.—(21.2.2).

POWER PLANTS

Study of screeching combustion in a 6-inch simulated afterburner. P. L. Blackshear et al. N.A.C.A. T.N. 3567 (*Oct.* 1955).

The mode of oscillation in a screeching 6 in. diameter simulated afterburner is identified through axial, circumferential, and diametric surveys of sound amplitude and phase. This mode is found to be the first transverse (sloshing) mode in the hot gases downstream of the flameholder. The development of a microphone probe suitable for use in screeching combustors is described. This development includes a theoretical and experimental treatment of the attenuation of high-amplitude sound in tubes.—(27.1).

Amplitude of supersonic diffuser flow pulsations. W. H. Sterbentz and J. Davids. N.A.C.A. T.N. 3572 (*Oct.* 1955).

A theoretical method for evaluating the stability characteristics and the amplitude and frequency of pulsation of ramjet engines without heat addition is presented. Theory and experiment show that the pulsation amplitude of a high-mass-flow-ratio diffuser increases with decreasing mass flow. The theoretical trends for changes in amplitude, frequency, and mean pressure recovery with changes in plenum-chamber volume were experimentally confirmed.—(27.4).

Effect of exhaust-nozzle ejectors on turbojet noise generation. W. J. North and W. D. Coles. N.A.C.A. T.N. 3573 (*Oct.* 1955).

Engine noise levels and jet velocity profiles have been obtained with several turbo-jet exhaust-nozzle ejectors. An insignificant reduction in total sound power was realised. At subsonic nozzle pressure ratios, total sound power from exhaust-nozzle ejectors or bypass exit configurations can be calculated from primary-jet parameters only.—(27.1).

Burning velocities of various premixed turbulent propane flames on open burners. N.A.C.A. T.N. 3575 (*Oct.* 1955).

Turbulent burning velocities were measured as a function of Reynolds number for open propane flames. Flames of propane and oxygen diluted with nitrogen, argon, or helium were studied in a variety of burners up to a maximum pipe Reynolds number of 26,000.—(27.1).

PRODUCTION ENGINEERING

Metal bonding of assemblies for the Canadair CL-28 maritime reconnaissance airplane. J. J. Waller. I.A.S. Preprint No. 573 (*Nov.* 1955).

This paper describes the introduction of bonding as a production process at Canadair Ltd. in the fabrication of the maritime reconnaissance adaptation of the Bristol "Britannia."—(28).

PROPELLERS

Theoretical study of the effect of forward speed on the free-space sound-pressure field around propellers. I. E. Garrick and C. E. Watkins. N.A.C.A. Report 1198 (1954).

The sound-pressure field due to thrust and torque of a propeller in flight at uniform subsonic speed is analysed by use of a distribution of acoustic doublets located at the propeller disc. The basic element used to synthesise the field is the pressure field of a concentrated force moving uniformly at subsonic speeds, for which an expression generalising one of Lamb's for the fixed concentrated force is given.—(29.0).

STRUCTURES

Unique structural problems in supersonic aircraft design. F. P. Mitchell. I.A.S. Preprint No. 568 (*Nov.* 1955).

Some structural problems involved in the design of supersonic aircraft are considered under the general headings of load analysis, aerodynamic shape, fatigue, internal pressure, landing gear, aerodynamic heating and use of new materials. —(33.0).

THEORY AND ANALYSIS

See also MATERIALS

Stress considerations in the design of pressurised shells. E. H. Mansfield. C.P. No. 217 (1955).

The design and stress analysis of pressurised thin-walled shells are considered with special reference to openings in the shell wall.—(33.2.4.3.7).

*The stress analysis of flat stiffened panels with cut-outs. B. C. Hoskin. A.R.L./SM.*3 (*February* 1955).

Several methods that have been developed for the stress analysis of flat stiffened panels are described in considerable detail. "Stringer-sheet," "finite-stringer," "PIBAL," "substitute-stringer," and "strain energy" methods are all discussed, and for each of these the assumptions are stated, the basic theory is developed, an indication is given of problems that have been solved and at least one illustrative example is presented.—(33.2.4.6.1).

Optimum structural design of wing box beams. S. Bernstein. I.A.S. Preprint No. 569 (*Nov.* 1955).

The following types of construction used for compression covers on wing box beams are analysed:—(1) Skin and Z-section stringers, (2) Double skin and corrugated panels, and (3) Solid plate multi-web construction. Curves of maximum compressive stress against the "Structural Index" are calculated and design data charts are derived to help select the most efficient rib or web spacing as well as the actual dimensions of the panel elements.—(33.2.4.1.0).

Experiment and theory in the investigation of the behavior of structures at high temperatures. N. J. Hoff. I.A.S. Preprint No. 572 (*Nov.* 1955).

An account is given of the new problems that arise when aerodynamic heating results in high temperatures in the structural components of supersonic aircraft. In particular, creep, thermal stresses, and buckling in consequence of creep or thermal stresses are discussed. Experimental equipment in use at the Polytechnic Institute of Brooklyn in the investigation of the high temperature problems is described.—(33.2.4.0.9).

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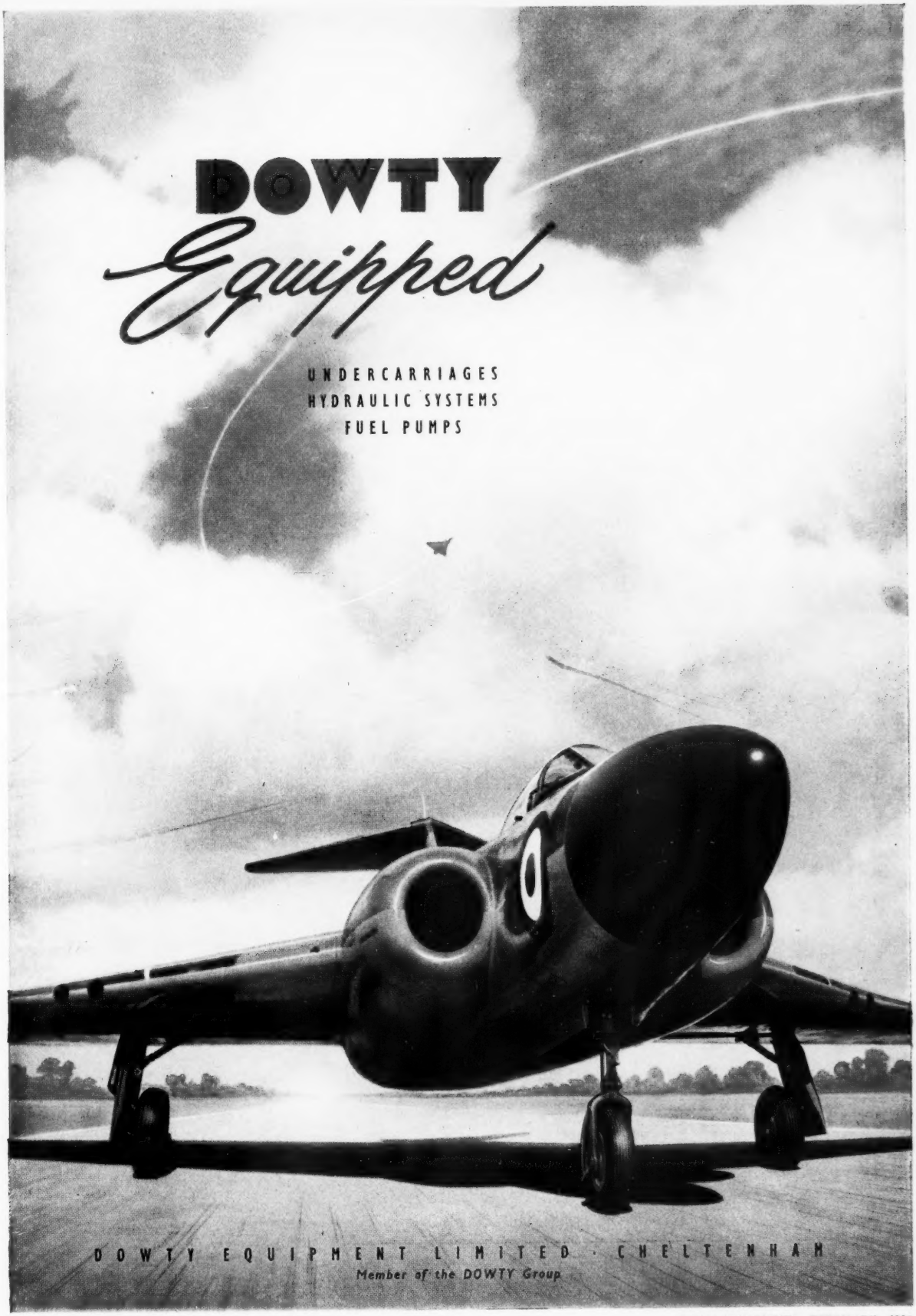
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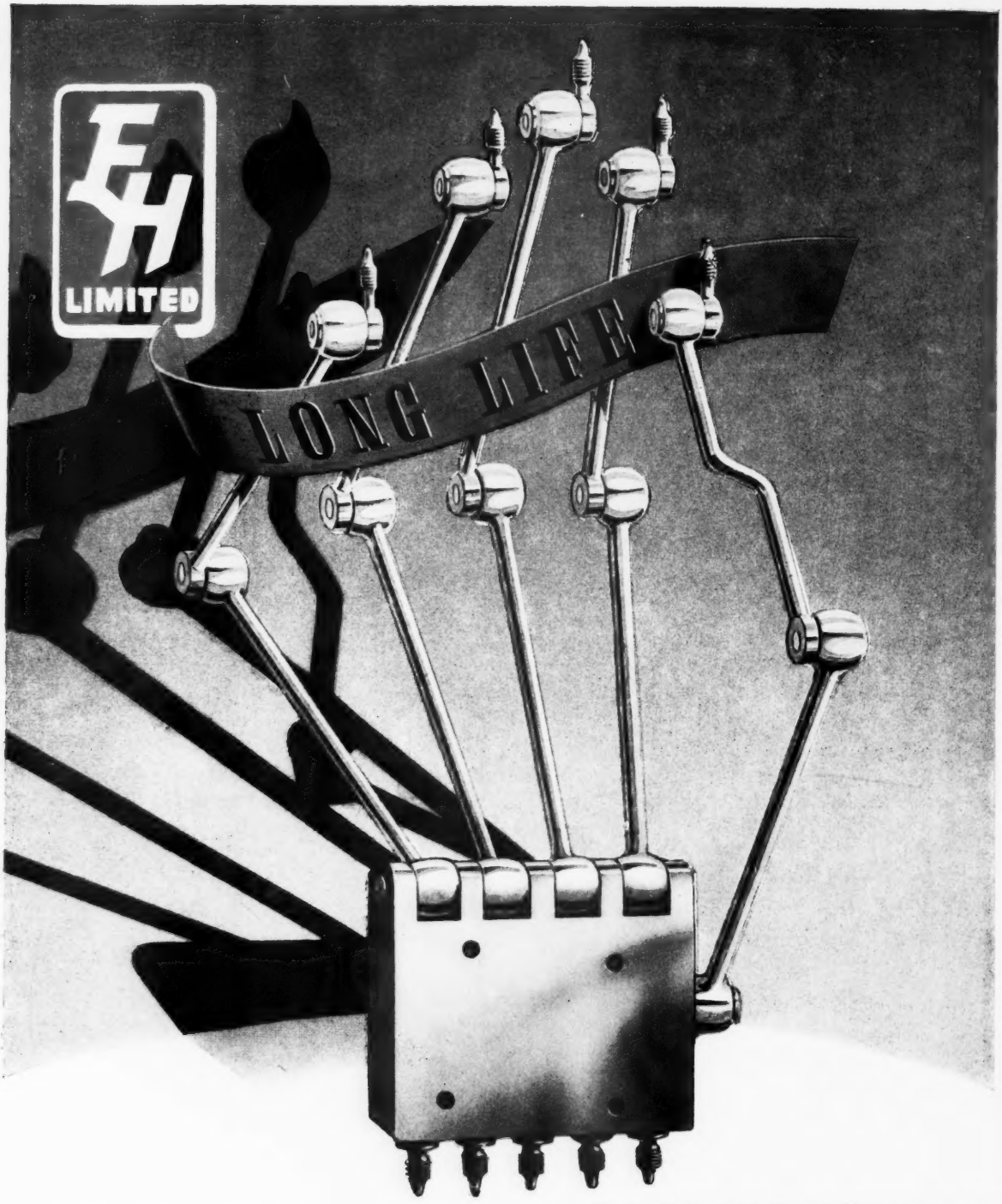

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